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GEOLOGY OF A MIDDLE DEVONIAN CANNEL COAL FROM SPITSBERGEN

BY

THOROLF VOGT

WITH 3 FIGURES IN THE TEXT

Abstract: A synopsis is given of the stratigraphy of the Middle Devonian beds of Mimer Valley, Central Spitsbergen, and a description presented of an occurrence of cannel coal in this series. The coal occurs just below beds with Asterolepis, belonging to the upper part of Middle Devonian. Large tree-shaped Lepidophytes of this age are also found. The early appearance of this „Upper Devonian" flora element is discussed. It is pointed out that the Middle Devonian sediments consist of much more weathered mineral grains than the sediments of Lower Devonian. The possible influence of the immigrating woods of Middle Devonian on chemical weathering is mentioned.

On his expedition to Spitsbergen in 1928, the present author studied, *inter alia*, the Devonian formation of Mimer Valley (Mimerdalen), at Billen Bay (Billefjorden), on the north side of the Ice fjord. He discovered here, in Middle Devonian beds, a seam of coal, representing, from the investigations of Horn (1941), a cannel coal, which may be of interest especially on account of its old age. A description of the geology of this coal bed will be given. As regards the previous geological work on the Devonian formation of the Mimer Valley reference may be made to the papers of Nathorst (1884, 1894, 1910), and to the paper of Stensiö (1918).

Synopsis of the Middle Devonian Stratigraphy of the Mimer Valley Area; Eastern Development.

In order to place the coal seam in the series, a synopsis will be given of the Middle Devonian beds in question, based on my observations in 1925 and 1928.

The Devonian beds of the Mimer Valley may be divided into a Lower and a Middle Devonian series, separated by a break. The sedimentary rocks of the two series are strikingly different. The rock material of the lower series is not much weathered, the sandstones often containing fresh felspars in great quantity, whereas the rock material of the upper series is heavily weathered, the sandstones generally only with "kaolinized" remnants of felspars. The rocks of the lower series clearly represent a more or less rapidly transported and deposited material. The material of the upper series was, on the contrary, subjected to the weathering during a long space of time. Both series are generally of continental character.

A western and an eastern development is discernible for the lower as well as for the upper series. In the lower series, the red and green Porolepis Sandstones, beds *d* and *e* of Stensiö, are increasing considerably in thickness towards the west, as indicated by my observations in the Hugin Valley—Dickson Bay area. As to the upper series, the lower part of the western development includes several beds which are not found at all in the east. These beds are thought to represent a part of the lost interval in the east. This is in accordance with the fish fauna, as partly described by Heintz (1929), of the Huginaspis Pass (between the Munin and Hugin Valleys), which belongs to the western development. The occurrence of a Huginaspis, (*Huginaspis Vogti* Heintz), especially indicates a smaller paleontological break between the two series in the west than in the east. Also other diversities occur, e. g. the disappearance, as far as is known, of the black shales towards the west.

The fossils mentioned in the present paper are given from the papers of Stensiö, (1918 a, 1918 b) and Heintz (1929, 1935), and from personal communications by A. Heintz (the fishes), and O. Arbo Høeg (the plants).[1] It may perhaps be mentioned that the most important fossil finds on my expeditions in this area were the discovery of the Devonian flora at Plantekløften (Plant Ravine), by A. Heintz, F. Isachsen, and myself in 1925, and of the flora to the south of Fiskekløften (Fish Ravine), by O. Arbo Høeg, T. Strand, and myself in 1928.

The following succession represent the eastern development, as exposed at the Estheria Hill, at the Plant Ravine, and at the Fish Ravine (vide the map fig. 1). Above the green Porolepis Sandstone (bed e of Stensiö), of Lower Devonian age, follow:

1. Gray sandstone in thick beds, total thickness about 5 m in the profile on the east side of Estheria Hill. These beds are, pro-

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[1] Tree-shaped Lepidophytes are mentioned also from my own diaries.

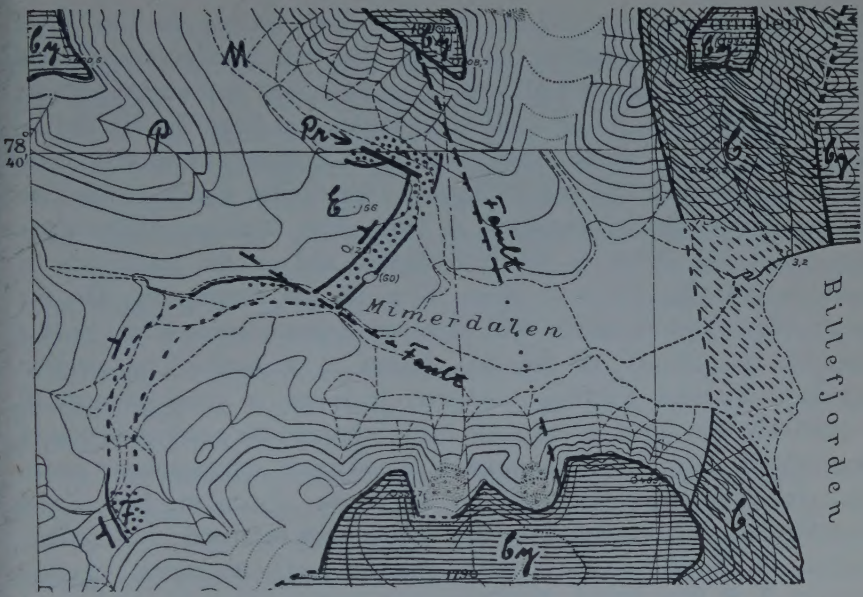

Fig. 1. The central part of Mimer Valley. Scale 1 : 75000. The dotted area between the two lines represents the Middle Devonian beds 1—6. Otherwise the Devonian beds are left unmarked. C = Culm beds. Cy = Cyathophyllum Limestone. M = Munin River. P = Plant Ravine (Plantekløften). E = Estheria Hill. F = Fish Ravine (Fiskekløften). Pr = the profile fig. 2. Topography from map 23 published in: Report of the Svalbard Commissioner concerning the Claims to Land in Svalbard. Part I. B. Oslo 1927.

visionally, interpreted as the basement beds of the Middle Devonian Series.

2. Black shale I with concretions of clay ironstone (bed Sk. I of Stensiö). This bed is exposed on the east and south side of Estheria Hill, in the latter locality with a thickness of about 20 m. From this bed are reported *Psammosteus* (*Psammolepis?*) *spinosus* n. sp., fragments of great Crossopterygii, and jaws of Coccosteids (?).

3. Yellowish gray sandstone, about 2 m and 1.5 m thick, respectively on the east and south side of Estheria Hill (bed f_1 of Stensiö).

4. Black shale II, (bed Sk. II of Stensiö). This brownish black shale, with concretions of clay ironstone, is exposed on the east side, to the northeastern corner, and on the south side of Estheria Hill. In the latter locality the thickness was about 30 m.

5. Yellowish gray, rather coarse sandstones, disclosed on the north and south side of Estheria Hill, with a thickness of about

60—70 m, respectively 30 m, near the Fish Ravine etc. (bed f_2 of Stensiö). These sandstones contained the first smaller tree-shaped Lepidophytes, and the bed of cannel coal described in the next section.

6. Black shale III (Fish Ravine Shale, and beds Sk. III and IV of Stensiö). A brownish black shale with concretions of clay ironstone, representing the bed extremely rich in fish fossils at the Fish Ravine, discovered by Nathorst in 1882. The thickness of this shale was about 15—20 m at the Fish Ravine and on the south side of Estheria Hill (Sk. III), and about 30 m on the north side. On the south side of the Estheria Hill, this bed appears twice in the profile (Sk. III and Sk. IV of Stensiö), owing to a fault. The western exposure contains *Estheria nathorsti* R. Jones, in great quantity in a relatively thin layer in the shale itself, whereas the eastern exposure has yielded *Asterolepis scabra* (A. S. Woodward), *Psammolepis undulata* etc. from concretions of clay ironstone. From the bed of the Fish Ravine itself, the following fish remains are reported: *Asterolepis scabra* (A. S. Woodward 1891), *Psammolepis undulata*, *Onchys arcticus* A. S. Woodward, *Dictyonosteus arcticus* Stensiö, *Holonema cf. radiatum* (Obručev), Rhizodontide scales, Dendrodont teeth, Glyptolepis scales (?), Coccosteide jaws, etc. Nathorst further reports on tree-shaped Lepidophytes.

7. Then follows a very characteristic division of green argillaceous sandstone (bed h of Stensiö), about or somewhat more than 100 m thick. It contains *Asterolepis cf. scabra* (A. S. Woodward), *Psammolepis undulata*, and of plants *Psygmophyllum* (or *Platyphyllum*) *williamsoni* Nathorst, and the first great Lepidophytes in Bergeria preservation.

8. The next division (bed i of Stensiö), consisting principally of sandstones with subordinate beds of shales and conglomerates, may probably be more than 400 m thick. It begins with 8 a: the lower Svalbardia Sandstone, a yellow sandstone, well exposed in the canyon to the south of the Fish Ravine, at this locality about 20 m thick, and rich in plants. Here occur a great tree-shaped Lepidophyte, with stems about 10 cm across, viz. *Bergeria mimerae* Høeg, and further a *Svalbardia* n. g. Høeg, displaying similarities to Kiltorkensia. This sandstone is superimposed by 8 b: a green shale, about 10 m thick, followed by 8 c: a violet sandstone. The succeeding beds are not present in this canyon, and were only poorly exposed in the profiles. I have studied them across the Estheria Hill to the Plant Ravine.

Above the frequently dark violet sandstone follow yellow sandstones, dark green sandstones, and conglomerates, with pebbles of quartz and quartzites, but also of non-metamorphic sandstones, possibly of Devonian age. Beds of green shales seem to be present in the series, to judge from disintegrated débris among the covering morainic drift.

Near the top, beds rich in plants again occur, the Upper Svalbardia Sandstone, viz. a yellowish green sandstone with well preserved plant remains: the same species of Lepidophyte, *Bergeria mimerae* Arbo Høeg, and the same new species of Kiltorkensia as in the lower bed. Further, a *Psygmophyllum* (or *Platyphyllum*) sp., a new genus named *Enigmophyton* Høeg with the aspect of a great Psygmophyllum, *Hyenia Vogti* Høeg, and a small Lepidophyte, *Protolepidodendropsis pulchra* Høeg.

9. The following division, the Plant Ravine Conglomerate, (bed m of Stensiö), represents a very peculiar conglomerate, as it seems with a thickness of more than 100 m, well exposed at the Plant Ravine, and also farther to the north. The well rounded conglomerate stones, up to about 35 cm in diameter, are lying close together in a dark and very friable sandstone matrix, and consisting almost exclusively of a gray, non-metamorphic sandstone, possibly of Devonian age. It contains thin layers of friable dark sandstone, dark shale with concretions of clay ironstone, and also coarse yellow sandstone. In the latter, indeterminable plant remains are found. This conglomerate includes the youngest known beds of the Devonian formations of the Mimer Valley area and of Spitsbergen.

The Coal Seam at Estheria Hill.

Along the Munin River, on the north side of Estheria Hill, a section through Middle Devonian beds is exposed. The eastern termination of the profile corresponds with the acute northeastern corner of the Estheria Hill area, where the river turns sharply to the south. To the west, the rocks are increasingly covered with morainic drift. The designation of the beds follows the stratigraphical members of the previous section. From ESE to WNW the following beds are exposed (vide fig. 2):

4. Brownish black shale, with yellowish brown streak, representing the upper about 10 m of the Black shale II. To the south of the corner, the river runs for a distance almost parallel to the strike of this bed.

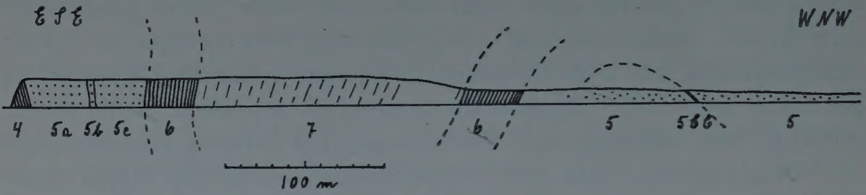

Fig. 2. Profile from the north side of Estheria Hill, along the Munin River. 4 = Black shale II. 5, 5a, 5c = Yellowish sandstone, with dark sandstone (5b), and seams of cannel coal (5CC). 6 = Black shale III (the Fish Ravine Shale). 7 = Green argillaceous Asterolepis Sandstone

5a. Yellowish gray sandstone with a yellowish coat of weathering, consisting prinicpally of quartz grains, with „kaolinized“ felspars in minor quantity. Thickness about 35 m.

5b. Dark, at least partly olive-green, sandstone. Thickness about 4 m.

5c. Yellowish gray sandstone like 5a, thickness about 30 m. The beds 5a and 5c contain fairly large, undeterminable plant remains, as do also the corresponding beds on the south side of Estheria Hill. The latter sandstones are similarly partly yellowish gray with a yellow coating, but also partly dark gray with a whitish coating.

6. A brownish black shale with numerous concretions of clay ironstone, representing the Black shale III (the Fish Ravine Shale) in inverted position. Thickness about 30 m.

7. Then follows, in the central part of the syncline, the distinctive green argillaceous Asterolepis Sandstone, to the east in inverted position. The strike of the western part of these beds, and of the beds further to the west, cross the profile intersection at a more or less acute angle. The green argillaceous sandstones are exposed over a length of about 130 m; then to the west follows a covered part of about 35—40 m with numerous blocks of this sandstone.

6. A black shale, probably representing the Black shale III, poorly exposed over a length of about 35 m, after which about 25 m wholly covered ground follows.

5. A yellowish sandstone, very poorly exposed, in many places only evidenced by numerous angular blocks, over a length of more than 150 m.

5 CC. The seam of cannel coal, exposed about 85 m from the first appearance of the numerous sandstone blocks, and about 110 m

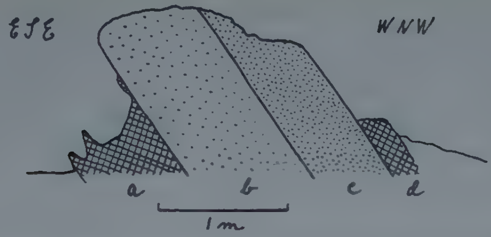

Fig. 3. The cannel coal exposure of the profile fig. 2. a and d = pure coal. b = dark sandstone. c = sandstone containing coal.

from the last exposure of the black shale. The strike of the coal seam is SSW, the dip about 55° to WNW.

From below follow (vide fig. 3):

a. 0.65—0.70 m pure coal
b. 0.80 m dark sandstone
c. 0.50 m sandstone containing coal
d. 0.20 m pure coal

The ground immediately below and above these beds was covered with drift.

The coal was wholly massive, without visible stratification, and rather strong and firm. In the sandstone near the coal layers was found a small tree-shaped Lepidophyte. It is possible that the coals and the accompanying dark sandstones correspond to the dark sandstone 5b farther to the east.

General Remarks. On The Early Appearance of the tree-shaped Lepidophytes.

The age of the fish fauna of the Fiskekløften Shale (Fish Ravine Shale = Black shale III) has been much discussed. The fauna was formerly considered to belong to the Upper Devonian by Nathorst (1910), Stensiö (1918 a, 1918 b), and Heintz (1935), whereas it is now referred to the upper part of Middle Devonian by Säve-Söderberg (1932, 1934, 1937 a and b), Heintz (1937), and Stensiö (Stensiö and Säve-Söderberg 1938). My own paper (1928 p. 112), where the Middle Devonian affinities of the fauna and flora of these and superimposed beds are pointed out, may, perhaps, also be mentioned. Based on the large *Asterolepis scabra* (A. S. Woodward), Säve-Söderberg (1937 b p. 30—34) refers the present zone to the Old Red Asterolepis beds, including the Nairn beds of Moray Firth, the John o'Groats Sandstones of Caithness, the Eday Sandstone of the Orkneys, the Brindister Flags of Shetland, and Dm_4 and Dm_5 of the Baltic states. This age determination refers to the Fish Ravine shale (6) and to the superposing green argillaceous Asterolepis sandstone (7).

The coal bed and the first tree-shaped Lepidophytes are found in the yellowish sandstone (5) below the Fish Ravine shale. According to Horn (1941) the coal principally represents a spore coal, laid down in more or less stagnant waters. These stagnant waters indicate marked continental conditions, with dry land in the immediate neighbourhood. The coal further indicates a rather dense vegetation at this time, consisting, at least partly, of smaller tree-shaped Lepidophytes. The first real, great tree-shaped Lepidophytes are found in beds, which, from the fish fauna are estimated to belong unquestionably to Middle Devonian, viz. the green Asterolepis Sandstone (7).

The beds above the green Asterolepis Sandstone do not contain determinable fish remains, the age being therefore more uncertain. According to information given by Arbo Høeg, Hyenia represents a typical Middle Devonian flora element, whereas *Svalbardia*, and still more the great Lepidophyte (*Bergeria Mimerae*) and *Protolepidodendropsis pulchra,* represent Upper Devonian flora elements. These beds may belong to the transition beds between Middle and Upper Devonian, as suggested by me before (1928). Or they may, and this is perhaps the most natural, belong to the upper part of Middle Devonian (the Asterolepis beds).

Even leaving the latter plants out of the discussion, it is a remarkable fact that so important an Upper Devonian flora element as the tree-shaped Lepidophytes (Lycopodiales), appears as early in Spitsbergen as in ascertained Asterolepis beds, or in upper part of Middle Devonian.

In Europe proper, similar "Upper Devonian" flora elements have, in appearance, not been found in Middle Devonian beds. This may give a slight indication as to a more proximate position of these northern areas to the centres of evolution of the mentioned flora elements than the more southern areas. The extremely rich development of the real Upper Devonian flora at Bear Island, also with coal beds, may perhaps give a hint in the same direction.

On the American side, another "Upper Devonian" flora element is found in beds now classed as Middle Devonian. The famous tree-stumps of Eospermatopteris at Gilboa, Schoharie Valley, New York, formerly considered Upper Devonian, belong, from the recent investigations of C. Arthur Cooper (1933—34, vide also Størmer 1934) to the upper part of Middle Devonian (Windom member of the Moscow formation, Hamilton group).

The development of the Devonian floras may have been connected with the rising lands of, largely or partly, late pre-Devonian mountain chains, the Old Red beds being regarded as postorogenic sediments from the new-formed mountains and hills. One may assume the existence of such a mountain chain from Spitsbergen, along the East coast of Greenland to Newfoundland and the Appalachians. It seems at present, in my opinion, to be possible that the mentioned land-belt may have played a prominent rôle in the development of the Upper Devonian floras.

Another feature, probably concerning the old vegetations of Spitsbergen, may be pointed out. As mentioned above, the mineral grains of the sediments, especially the sandstones, of the Lower Devonian series, were not much affected by chemical weathering, the felspars generally being preserved fresh and unaltered. This fact may be ascribed to a rapid transportation and sedimentation of the sands and muds, leaving the atmospherical factors only a comparatively short time to act on the mineral grains. This rapid transportation agrees well with the conception of semi-desert conditions which may have prevailed in Lower Devonian time, not by reason of shortness in precipitation, but owing to the existence of only sparse vegetation. Reference may be made to an earlier discussion by me on this topic, as to pre-Cambrian land surfaces without vegetation (1924 pp. 328—29, 369—70).

In contrast to the conditions of the lower series, the mineral grains of the Middle Devonian sediments are heavily weathered, the sandstones generally only containing decomposed remnants of felspars. The sands of these rocks were clearly subjected to chemical weathering during a long space of time. This marked change in external conditions from Lower to Upper Middle Devonian may have various causes. The Lower Devonian sediments were generally of postorogenic character, the basins of sedimentation being surrounded by relatively steep mountains, giving a rapid transport of the sands. In the course of time, these mountains were, however, denuded, giving a slower transport of the detritus. The climate may also have changed in the direction of greater warmth and humidity. It may, however, be pointed out that a more continuous cover of vegetation will also involve a slower transportation of the débris and an intensified chemical action on the mineral grains. Indirectly, the immigration of woods would also suggest some change of the climate. I have a strong impression from my field work of the generally great contrast between the quantity and type of vegetation in the Lower, and the quantity and type of vegetation in the Middle Devonian in these areas, and I would also in this connection stress the importance of the cover of vegetation.

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PETROLOGY OF A MIDDLE DEVONIAN CANNEL COAL FROM SPITSBERGEN

BY

GUNNAR HORN

WITH 1 PLATE

In 1928 the Norwegian geologist Th. Vogt discovered a seam of coal in Middle Devonian beds in Mimer Valley at Billen Bay (Billefjorden) on the north side of Ice Fjord, Spitsbergen. The geology of this area and the geological position of the coal have been exhaustively dealt with by Vogt himself (1941) to whose paper on the subject I beg to refer. Samples of the coal were handed to me for description.

The macroscopic appearance of the samples indicates coals of the same general character. They are homogeneous and with a more or less even fracture. The colour is dull blackish with a brownish shade, and the streak is distinctly brown. Tiny specks and streaks of shining coal are common. The coals are compact and tough, rather hard, traversed by a few joints, and much slickensided, so that the coal usually breaks into lumps limited by such features. The joints and slickensides are often stained brown from iron oxides. The specific gravity of a piece appearing to represent the average was determined at 1.316, i. e. the same as for bituminous coals. The brown streak might suggest that our coals were of the brown coal rank[1], but neither boiling with a potassium hydroxide solution (N. KOH) nor with diluted nitric acid (10 per cent. HNO_3) produced any brown or yellow colouring of the fluid, so that our coals are of the rank of true coal (*Steinkohle*). They can be kindled by the application of a match.

As the coals are compact and tough, polished and thin sections were easy to make. When viewed in polished section and reflected light (Pl., Fig. 1) the coal is seen to consist of fine-grained organic constituents with some grains of quartz (having a marked relief).

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[1] *Rank* defines the position of the fuel in the series peat-anthracite. It shows the degree of metamorphism. The *type* of a coal is determined by the kind of plant material from which it originated.

Streaks of vitrinite (from fragments of woody matter) and some megaspores are also seen. It is, however, only in thin section that the true botanical nature of the coal is readily recognized. It consists almost entirely of the flattened spores of plants, and thus differs markedly from ordinary coal. Photomicrograph Fig. 2 (Pl.) shows a thin section of this spore coal, and Fig. 3 the same when viewed under a high magnification. The spores have commonly a length of 0.02 to 0.1 mm, and they have a more or less subparallel arrangement. They are compressed and partly interlocked, and humic matter is apparently distributed throughout the mass. The toughness of the coal is thereby easily explained. Some yellow bodies of bitumen also occur. Dark streaks and patches probably represent substance high in ash. Between crossed nicols the many grains of semi-angular quartz become conspicuous, and minute flakes of muscovite are also present. These mineral constituents occur scattered throughout the coal mass.

A powdered sample was oxidised for a week with Schulze's solution (conc. nitric acid + potassium chlorate). The coals were easy to macerate. The residue was washed in water and treated with ammonia, whereby the oxidised material was dissolved leaving a residue consisting almost exclusively of small spores and their fragments. In addition to these were some indistinct fragments of cuticle (?), and grains of quartz and some muscovite. On one spore were seen the triradiate ridges, these being the imprint of the three other spores of the tetrad.

From the above it is clear that the Mimer Valley coal is a *cannel,* although it has not quite its typical macroscopic appearance. The typical cannel has a marked conchoidal fracture and a dull, somewhat greasy or satiny lustre; but a high ash content would make this appearance less characteristic. A cannel coal is, above all, fine-grained, and in thin section is seen to consist of spores and subordinate other plant remains such as cuticle, resinous substance, fragments of woody matter. With this our coal agrees well. As will appear from the analyses below, the chemical composition is also typical cannel: extremely high content of volatiles and hydrogen, and a very high yield of tar[1]. The cannel coal from Mimer Valley was analysed by Mr. Ole A. Løkke of the Norwegian State Railway's Chemical Laboratory:

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[1] Boghead coals have also an extremely high yield of volatiles and tar, but are microscopically different from the cannels. They consist chiefly of "yellow bodies" ("algal bodies"). Cf. Horn (1931), Bode (1932), and Skilling (1938). Some cannels also contain subordinate amounts of these "algæ".

Proximate:

		On moisture-and ash-free basis
Moisture	0.9 per cent.	
Ash	21.2 —	
Fixed Carbon (Coke less ash)	29.7 —	38.1 per cent.
Volatile Matter	48.2 —	61.9 —
	100.0	100.0

Ultimate:

Moisture	0.9 per cent.	
Ash	21.2 —	
C	63.6 —	81.5 per cent.
H	5.7 —	7.3 —
O+N+S	8.6 —	11.2 —
	100.0	100.0
Gross calorific value	6 773 Cals. (12 191 B. t. u.)	8 694 Cals. (15 649 B. t. u.)
Net — —	6 461 Cals. (11 630 B. t. u.)	8 300 Cals. (14 940 B. t. u.)

The coke was intumescent and silver grey. The ash is greyish. This coking propensity distinguishes our coals from the usual cannels, which are generally considered as non-caking (pulverulent coke); but it should be borne in mind that by progressive coalification (*Inkohlung*) the cannel coke also commences to swell.

A sample has been assayed (by me) for yield of tar and low-temperature coke. For this purpose 25 gm. were placed in the aluminium distillation apparatus of Fischer-Schrader, and the temperature was gradually increased to 520° C. The result was:

Semi-coke	59.4 per cent.
Tar	28.3 —
Water	4.5 —
Gas and loss	7.8 —

The semi-coke was well sintered and rather firm. The water had an alkaline reaction. Referred to dry, ash-less coal the tar yield is 35 per cent. The yield of various cannels is given by Fischer and Schrader (1920) as 20—30 per cent. Our coals have thus a very high yield of tar. The Tertiary coals of the Kings Bay Field in Spitsbergen are also distinguished by being high in volatiles, averaging abt. 47 per cent (dry, ash-less basis) and the content of hydrogen is abt. 7 per cent. Their yield of tar by low-temperature distillation is abt. 20 per cent. Although these chemical data would suggest a cannel, they are nevertheless *not* cannels (Horn 1928, pp. 37—38), which have *physical* characteristics that the Kings Bay coals do not possess. The latter are macroscopically and in thin section very similar to ordinary Long Flame coals. The reason why the Kings Bay coals and some coals from the Central Tertiary Basin of Spitsbergen are so high in tar is not quite clear. In some way it must be connected with the presence of material with a high content of resinous and fatty substances.

A study of the position of our coals in the classification schemes shows that they fit in well as cannels. The classification of Grout (1907) is based on fixed carbon for coals above bituminous, and on fixed carbon and total carbon for bituminous coals and those of lower rank. According to this classification, cannel coals are those with a fixed carbon content of 35—48 per cent., and a total carbon of 76.2—88 per cent. Our coals with 38.1 per cent of fixed carbon and 81.5 per cent of total carbon thus fit well into this scheme. The Kings Bay coals have on the average a fixed carbon content of 53 per cent and 82.5 per cent of total carbon (Horn *loc. cit.*, p. 37). In this classification they would thus not come within the cannel class, but be classed as bituminous coal. Seyler (1928) uses on his carbon-hydrogen diagram lines of equal calorific value (isocals) and of equal volatile content (isovols). Cannels are here in the area above the line of 15 734 B. t. u. and of the line of vol. 47. The volatiles of our coals bring them well into the cannel class, but the cals. only to the border. The Kings Bay coals with an average of 47 per cent of volatiles and 14 913 B. t. u. are, however, below the cannel border in this classification. Bode (1931) has emphasized the need for *combining* the microscopic and chemical data when classifying the bituminous coals. In his cannel group (including the bogheads) the cannels proper have a ratio of carbon to hydrogen of 10—14 and a fuel ratio (Fixed Carbon to Volatile Matter) of 0.65—2.50. These figures for our coals are 11.2 and 0.62, and for the Kings Bay coals 11.8 and 1.13. A consideration of these chemical data alone, then, would lead one to believe that the coals were practically identical, but a microscopic study of them shows that they are quite different, the Kings Bay coals belonging to the group of banded bituminous coals. When classifying a coal it is thus essential to consider the chemical *and* the microscopic criteria.

How were our coals formed? As stated above, they consist of a uniform mass of spores with rather abundant mineral constituents. It is reasonable to assume that they were formed through deposition of vegetable mud in lakes and stagnant waters, too deep for subaerial vegetation, in the forests, and they are consequently in a way allochthonous, and not the product of normal peat accumulation. The base of the lowest coal layer has not been uncovered, but I think no under-clay representing an ancient soil upon which the plants grew would be found below it.

The spores were blown into the lakes and deposited and mixed with mineral matter and some plant débris washed into the collecting basins. This mode of origin makes it probable that the beds of cannel have only a limited extension and are more or less lenticular. But in the same sequence similar deposits may well occur elsewhere.

It is interesting to note that in Bear Island we have coals which may have a similar mode of origin. One of the Upper Devonian coal seams has in its lower part a peculiar dull, graphite-black, and massive coal having the appearance of the so-called "pseudo-cannels" (cannels changed by metamorphism). Its texture and appearance has led me to believe that it represents plant débris which has drifted into stagnant waters and deposited here along with mineral matter (Horn *loc. cit.*, p. 18). The mode of origin should then be similar to that of the Spitsbergen cannel, but the Bear Island pseudo-cannels seem to have a wider extension. In Bear Island, however, the coalification has progressed much further (as indicated by the low content of volatiles and the physical character of the coal), resulting in a deep black somewhat lustrous coal in which it is impossible or, at all events, difficult to recognize the botanical constituents. Spores could not be identified in this altered coal, which seems to consist chiefly of humic matter. The texture, however, is granular, making it probable that when the coal was of a lower rank (less metamorphosed) it had the appearance of a true cannel in spite of the probable (?) absence of spores.

A progressive coalification of the Mimer Valley cannel would, perhaps, produce a coal with a similar appearance.

The occurrence of beds of true cannel in the Upper Middle Devonian of Spitsbergen is of considerable interest, since they are, to the best of my knowledge, the oldest known cannels in the world.

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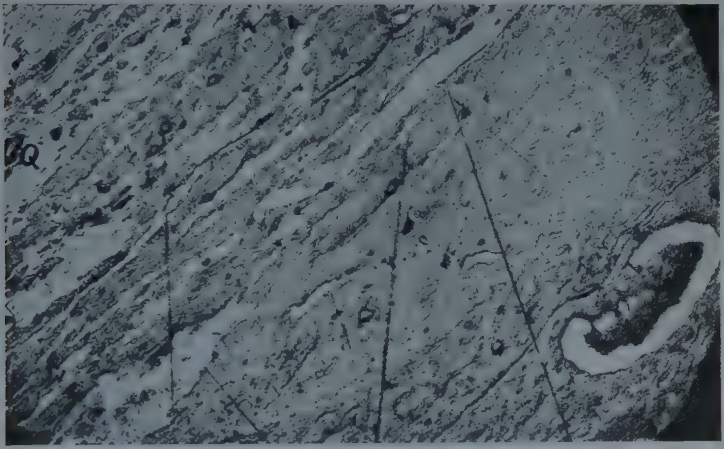
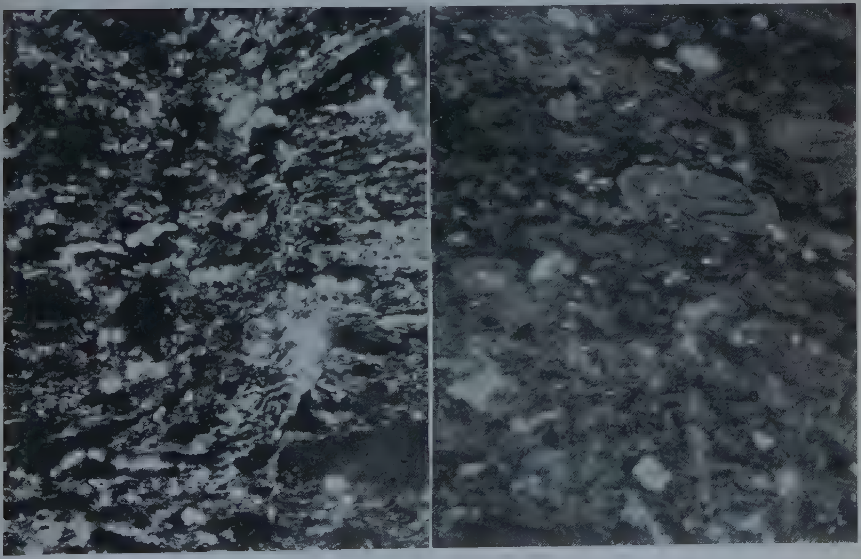


Fig. 1. Cannel coal. Fine-grained texture. Megaspore and streaks of vitrinite. Q = Quartz. Polished section. × 45.



2. 3.

Fig. 2. Showing the coal to consist chiefly of spores. Thin section. × 75.
Fig. 3. A more highly magnified view of the coal shown in Fig. 2. Subparallel arrangement of the spores. Light spots are quartz. Thin section. × 200.

Ms. rec. Nov. 23, 1940.

ARMENITE, A WATER-BEARING BARIUM-CALCIUM-ALUMOSILICATE

BY

HENRICH NEUMANN

WITH 4 FIGURES IN THE TEXT

Introduction: This mineral was originally found by cand. min. O. A. Corneliussen in 1877. He was aware of being confronted with something exceptional, but eventually he arrived at the conclusion that it was an epidote with an unusual habit, and labelled it "Epidote?". — While working on the Kongsberg-minerals, I found it in the collections of the university and made it subject to a more thorough examination. It is known only in a single specimen found in the Armen Mine at Kongsberg, and after that mine I have named it *armenite*.

Armenite is colourless or green and translucent to dull. The crystals are pseudohexagonal, with long prismatic habit and poorly developed terminal faces. They may attain a size of 1½ × ½ cm.

Chemical properties.

Tiny fragments of these crystals carefully examined for purity were chemically analyzed; the analysis was made by stud. mag. scient. Lars Lund, whom I want to thank for his excellent assistance. The purity of the precipitates was optic spectrographically controlled and the amount of strontium determined by civ. eng. A. Kvalheim, to whom I am also indebted. 0,5 gr. was used for the main analysis, and 0,5 gr. for the determination of alkalies. The composition is as follows:

	A	B
SiO_2	46,18 %	7690
Al_2O_3	27,52 -	2692
BaO	12,37 -	829
SrO	0,04 -	4
CaO	9,99 -	1781
Na_2O	0,16 -	26
K_2O	0,13 -	14
H_2O + ...	3,41 -	1893
H_2O —	0,11 -	
	99,91 %	

A; weight percents, B; corresponding molecular proportions.

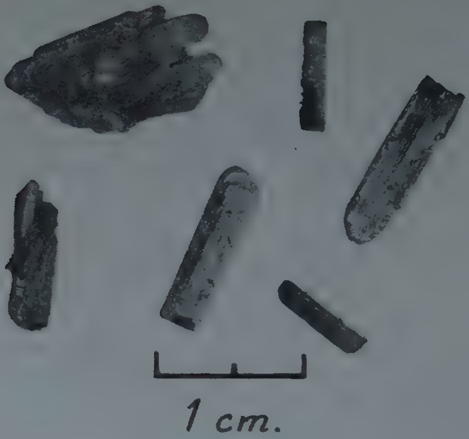


Fig. 1. Armenite crystals. The two upper crystals have small axinites on the prism faces. Photo by Unn Hofseth.

According to this the gross formula is (A):

$Ba\ Ca_2\ Al_6Si_8O_{28}\ 2H_2O$,

directly from the analysis

$Ba_{0,89}K_{0,03}Ca_{1,90}Na_{0,05}Al_{5,75}Si_{8,22}O_{28} \cdot 2{,}02\ H_2O$,

and after subtraction of alkalies:

$Ba_{0,92}Ca_{1,95}Al_{5,88}Si_{8,14}O_{28} \cdot 2{,}02\ H_2O$.

The gross formula may also be (B):

$Ba\ Ca_2\ Al_6\ Si_9\ O_{30} \cdot 2\ H_2O$,

directly from the analysis:

$Ba_{0,95}Ka_{0,03}Ca_{2,08}Na_{0,06}Al_{6,16}Si_{8,80}O_{30} \cdot 2{,}16\ H_2O$,

and after subtraction of alkalies:

$Ba_{0,98}Ca_{2,09}Al_{6,25}Si_{8,71}O_{30} \cdot 2{,}16\ H_2O$.

We see that formula A is in better accordance with the analysis, whereas B agrees with the formula type

(earth alkali) $Al_2Si_3O_{10} \cdot nH_2O$, a well-known type.

Physical properties.

As already mentioned armenite is pseudohexagonal with long prismatic development. The angles between the prism faces were measured on three crystals. They were all about 60°, ranging from 59°37′ to 60°45′ with an average deviation of 11′.

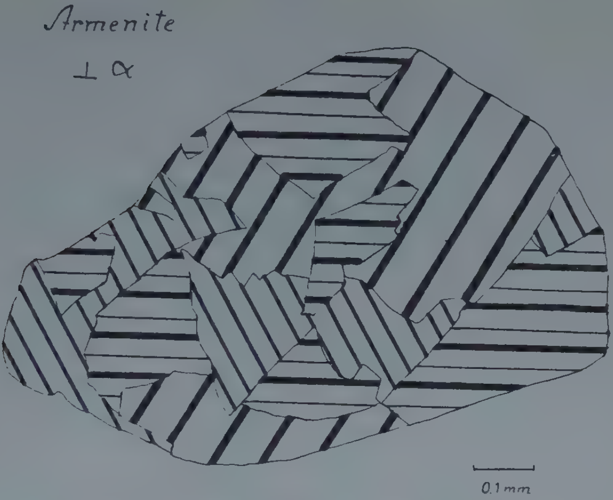


Fig. 2. Penetration twin of armenite, showing three individuals making an angle of 120° with each other.

The variation showed no regularity, and the deviations are most probably due to numerous vicinal faces that interfered with the measurements. The terminal faces were strongly corroded and therefore not measurable.

The refractive indices of armenite are rather low. Using the immersion method, in several crystals, I found $\alpha = 1{,}551$ and $\beta = 1{,}559$. It was quite impossible to find any section $\perp$ α or $\perp$ β, so γ could not be measured directly. The cleavage $\perp$ γ is obviously very marked, and, as earlier suggested by me (Norsk geologisk tidsskrift 19, p. 312), a cleavage $\perp$ α is probably non-existent. Then I had a thin section $\perp$ α made, and with Berek's compensator I measured $\gamma \div \beta = 0{,}0034$.

Based on these measurings I state:

$\alpha = 1{,}551 \pm 0{,}002$
$\beta = 1{,}559 \pm 0{,}002$
$\gamma = 1{,}562 \pm 0{,}002$

In several crystals the axial angle was measured with the universal stage, and the following values were found: 61,5°, 61°, 61°, 60°, 60°, 60° 59°, consequently $2V \div = 60° \pm 2°$. Computed from the indices, one finds $2V \div = 63°$, in good agreement with the measured values.

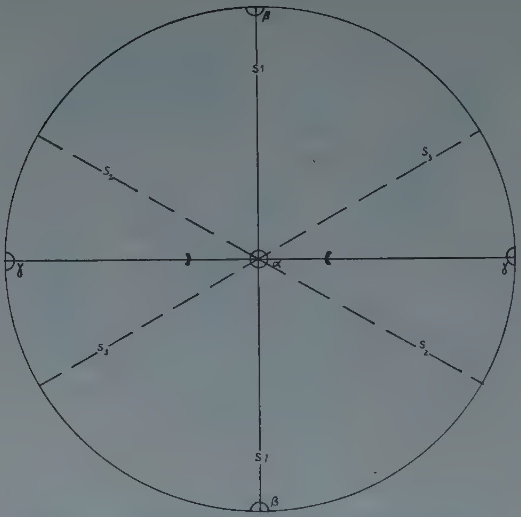


Fig. 3. Stereographic projection: S_1S_1 perfect cleavage. S_2S_2 and S_3S_3 indicates directions of less perfect eleavage.

Microscope examinations of the thin sections showed the pseudohexagonal crystals to be penetration twins composed of three optically biaxial individuals making an angle of 120° with each other (Fig. 2). Each individual possesses three tauto-zonale cleavage planes, one perfect (Fig. 3, S_1S_1) and two distinct ones (Fig. 3, S_2S_2 and S_3S_3). The angles between them are all 120°, and the zone axis is parallell to the pseudohexagonal axis, corresponding to the optical direction α; the best cleavage lies in the α-β-plane. (Fig. 3.) It is natural therefore to select the α-β-plane as one fundamental face and the zone axis (= pseudohexagonal axis, = direction α), as one crystallographic axis. Thus armenite would seem to be rhombic.

A probable explanation of these phenomena is that armenite is truly hexagonal at high temperatures, and on cooling, changes to a rhombic (?) low temperature modification.

Whether armenite on heating will become uniaxial, is not known.

The hardness of the mineral is between 7 and 8; the specific gravity was determined with a Westphal balance and heavy solutions. D = 2,76.

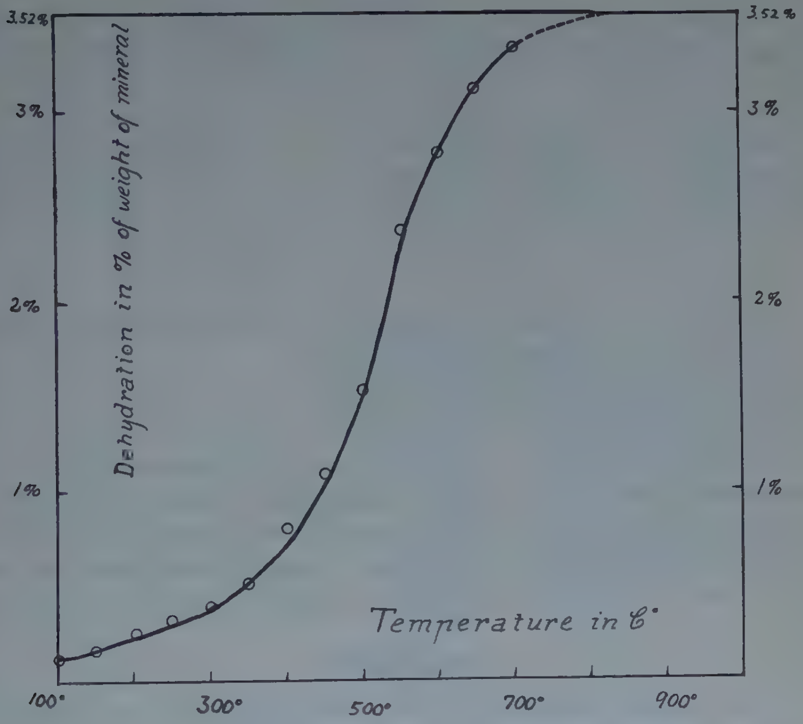


Fig. 4. Dehydration curve of armenite.

Discussion.

The systematic position of armenite is still uncertain. A first guess would be that a water-bearing earth-alkali-alumina-silicate should be a zeolite. To decide this, the hydration was examined. It was done as follows: 1,4 gr. armenite was powdered and heated for several hours at 105 C° to get rid of the hygroscopic water, then ½ hour at 150 C° and weighed, then ½ hour at 200 C° and weighed, and so on for every 50th degree. The resulting curve (Fig. 4) appears to be quite different from that of zeolites. It resembles the dehydration curve of sericite (Baker, James M., University of Toronto Studies, Geol. Ser. 40, p. 103). An important feature is that the greater part of water is expelled between 450° and 600°. The curve thus demonstrates that the water is not zeolitic.

Melting does not take place at a temperature available in a crucible over a teclu burner.

Armenite shows strong resemblance to milarite. Both exhibit hexagonal habit and are composed of rhombic (?) segments. The data are as follows:

	Armenite	Milarite
Cryst. syst.	Rhomb. (?) and hex.	Rhomb. and hex.
Formula	$BaCa_2Al_6Si_9O_{30}2\,H_2O$	$KCa_2Be_2AlSi_{12}O_{30}\frac{1}{2}\,H_2O$
n	1,56	1,53
H	7,5	6
D	2,76	2,6

To show the supposed isomorphism we may write the formulae

Armenite $BaCa_2AlAl_2Al_3Si_9O_{30} \cdot 2\,H_2O$

Milarite $KCa_2AlBe_2Si_3Si_9O_{30} \cdot \frac{1}{2}H_2O$

We see that in armenite the bivalent Ba (1,43 Å) replaces the univalent K (1,33 Å), and, in order to satisfy the valences, at the same time silica (0,39 Å) in the complex silica-oxygen-anion of armenite is replaced by alumina (0,57 Å) and in milarite by beryllium (0,34 Å).

In order to ascertain the systematic position and prove the possible relation to milarite, an x-ray investigation must be carried out.

Paragenesis.

The specimen examined shows, besides armenite, the following minerals: axinite, pyrrhotite, quartz, and calcite.

Armenite is first deposited, with the pseudohexagonal base nearly perpendicular to the wall of the vein. On armenite grow clear little crystals of axinite and quartz, and at last the vein is filled with calcite.

Pyrrhotite occurs in well developed crystals which have later been corroded. Also these seem to be younger than armenite.

Armenite is probably the oldest mineral in the paragenesis.

Aknowledgements. The experimental part of the present paper was done while I was connected with the Mineralogisk Institutt, whose director, professor Tom. F. W. Barth, as well as professor V. M. Goldschmidt, director of the Mineralogisk Museum, kindly placed the facilities of both institutions at my disposal.

The work was facilitated by grants from the Sulitelma Fund.

Norges geologiske undersøkelse,
Oslo, in November 1940.

Printed July 14th, 1941.

Ms. rec. Febr. 7, 1941.

THE LØNSET ANTICLINE IN THE OPDAL AREA

BY

IVAN TH. ROSENQVIST

WITH 8 FIGURES IN THE TEXT

Abstract: It is made reasonable that the basal gneiss in spite of the conformity is older than the granulite and of archean age. A conglomerate is found in a highly deformed condition between the flagstone and the gneiss. In an undeformed condition it occurs as an inclusion in the Gråhø saussurite gabbro. It contains inter alia fragments of the basalgneiss displaying its normal foliation. Since the gabbro is of Cambro-Silurian age, the conclusion must be that the conglomerate separates an arcean gneiss of pre- Caledonian foliation from the Sparagmitian granulite.

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INTRODUCTION

In the districts round and south of Lønset in Drivdalen in the Opdal—Sunndal district, Holtedahl in his paper Geological Observations in the Opdal—Sunndal—Trollheimen district (I)[1] has described a great anticline, formed by a gneiss complex conformly overlain by granulitic flagstones. These are most probable sparagmitic rocks of Eocambrian age in a very metamorphic state, corresponding to the well-known "Opdal-heller". He seems to be inclined to think

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[1] The Roman numerals refer to the list of literature p. 48.

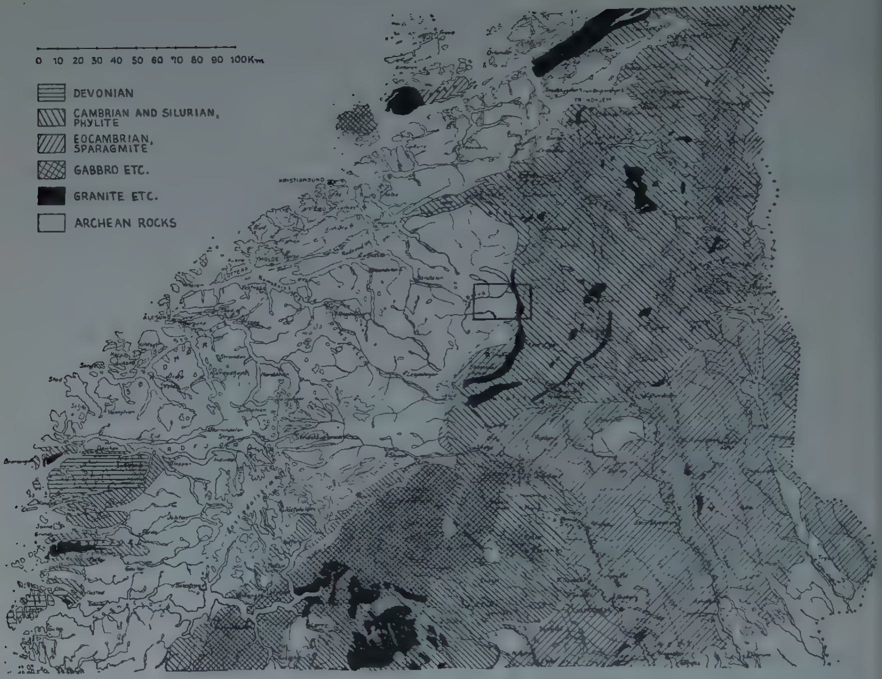
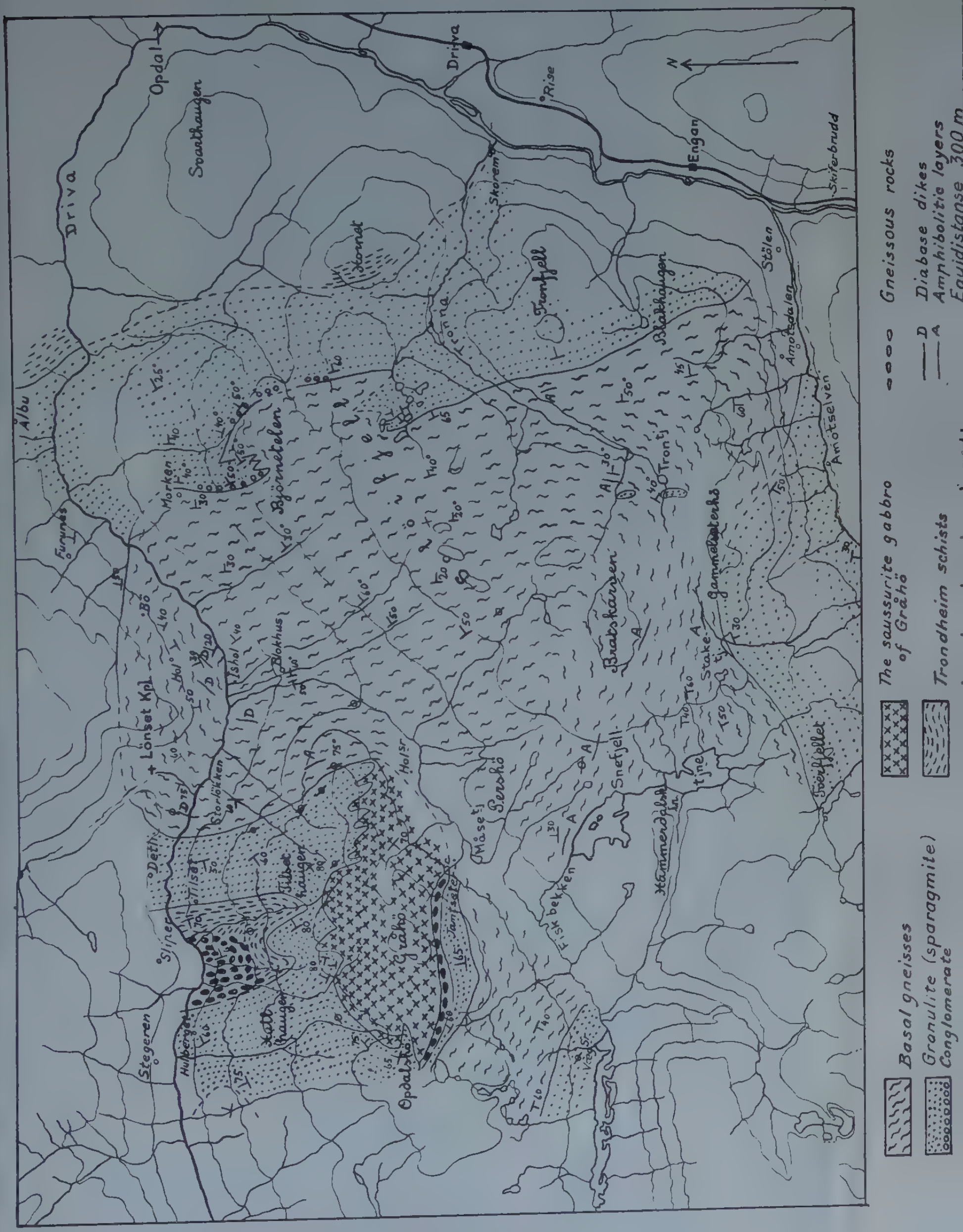


Fig. 1. Index map. After W. Werenskiolds map.

that also the basal gneisses are Eocambrian, representing deeper deposits, highly altered through migmatization. The area mentioned is on the usual maps of Norway and Scandinavia marked as pre-Cambrian. How much of the so-called "Romsdals grunnfjell" is of archaean age and how much is younger, was discussed after the presentation of Holtedahl's and Barth's papers at a meeting of Norsk geologisk forening, published in Norsk Geologisk Tidsskrift 18, 1938, p. 75—80. It was very much wanted to try to fix the age of the basal gneiss through a radioactive determination, and the professors Barth and Gleditsch asked me to undertake such an investigation. I have consequently carried out determinations of lead and radium in some rocks from this gneiss complex (given me by Professor Holtedahl) and I have sent the lead to a mass spectrographic determination. Because of the political situation, however, I have not yet got the result of this investigation. This work will later be published. For a year I worked with the chemical analyses of the rocks from the area, and in connection with Professor Holtedahl's field investigations I had


Driva
Opdal
Soarthaugen
Driva
Rise
N
Engan
Skiferbrudd
Skorem
Hornet
Tronfjell
Tronna
Blokhaugen
Stölen
Åmotsdalen
Åmotselven
Albu
Furunes
Morken
Bjørnetelen
Lønset Kpl.
Bö
Dal
Storlökken
Shol
Blokhus
Tronfj.
Bratskarven
Gammelsæterhs
Stake
Snefjell
Hammerdalsh.
tjne
Jöerfjellet
Detli
Tilset
Tilsethaugen
Slipen
Katthaugen
Stegeren
Hulbergen
Opdalsho
Gråhö
Jamtsæter
Måset
Gershö
Holsr.
Fiskbekken
Vegst.
D
A
Basal gneisses
Granulite (sparagmite)
Conglomerate
The saussurite gabbro of Gråhö
Trondheim schists
Gneissous rocks
Diabase dikes
Amphibolitic layers
Equidistanse 300 m

during the summers 1939 and 1940 an opportunity through Norges geologiske undersøkelse (The Geological Survey of Norway) to map parts of the Opdal sheet south of the river Driva. I want to acknowledge my gratitude for grants from *Familien Stillesens Legat.* The present paper is concerned with some of the results of this mapping and of the microscopic and petrographic work connected with it.

GEOLOGICAL OBSERVATIONS OF THE BASAL GNEISSES

These rocks consist, as already mentioned by Holtedahl (1) mainly of augen-gneisses, more or less schistous gneiss-granites, and banded gneisses, partly with amphibolitic layers. Holtedahl (I) has dealt with the road-section from Ålbu to Gjøra and in this connection he has described the basal-gneisses north of the river Driva.

The uppermost part of the basal gneisses, a little east of Bø farm, is made up of schistous augen-gneiss which dip fifty degree to N 25° E, and it is easy to discern the gneiss from the flagstone in NE because of the great biotite amount in the gneiss, whereas biotite is rare in the flagstone series.

West of Bø farm the dip of the gneisses gradually turns towards the north and becomes gentler. At Hol farm the dip is 40° in the direction NNW. Here stripes of amphibolite with a tickness of a couple of metres appear in the gneiss which is here more gneiss-granitic. The amphibolite layers can be followed in the direction of strike over long distances. Between Hol farm and Gravaune farm the rock is a light, fine-grained, schistous gneiss-granite, but about a hundred metres east of Gravaune it suddenly becomes strongly folded and rough, with mainly chlorite and hornblende as dark minerals. Here the dip is straight north and about 50°. On the western side, this rough rock disappears as suddenly as it appeared, turning into mainly augen-gneiss and gneiss-granite with strike varying from NE—SW to ENE—WSW and the dip ranging from 90° to 60°.

Some 250 metres east of Vindøla brigde a layer of gabbroic amphibolite with a thickness of about 50 metres is found. This amphibolite cuts through normal gneiss with a sharp fine contact. The amphibolite in the neighbourhood of the contacts is interwoven with lighter gabbroic veins.

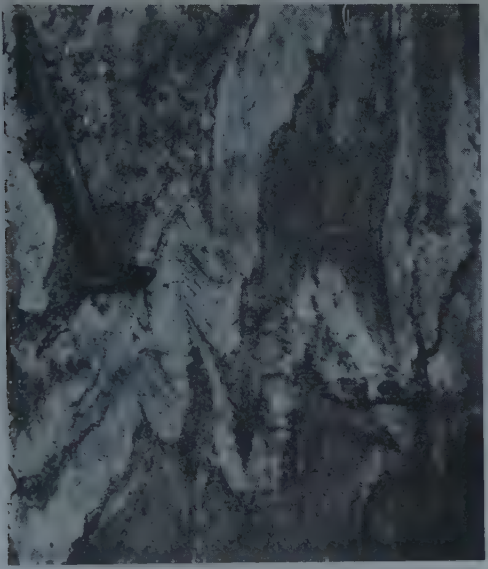


Fig. 3. Characteristic structural patterns, regarded as ptygmatic folds later deformed.

On both sides of the river Vindøla, between Vindøla bridge and the Driva, the gneiss is penetrated by lighter veins displaying ptygmatic folds which later were deformed. The gneiss has here a dip of 75° to NW. A little west of the bridge the gneiss is very rich in biotite and contains strongly folded quartz feldspar pegmatite veins. The boundary between the gneiss in the Vindøla and this biotite-rich gneiss is covered with loose deposits. The dark gneiss is an augengneiss with porphyroblasts of microcline up to a size of 3 centimetres. To the west along the road the gneiss is mostly dark and often penetrated by rather thick, lighter layers, partly with foggy boundaries, partly with sharp boundaries. Layers chiefly containing biotite, hornblende and epidote are also found. In the neighbourhood of the flagstone series there is a small amount of gneiss with muscovite, and some layers of red granitic gneiss (Fig. 4). The strike is, generally speaking, NNE, the dip varies from 90 to 80° westward. Near the boundary flagstone—gneiss the dip becomes gentler, about 60°.

The boundary is conform and is met with between the farms Detli and Trøen. From this place it extends southwards over the river Driva, past Storløkken farm and furtheron in the direction SSE up the north-eastern slope of the Storhaugen mountain and a little down on the southern side. In this area the gneisses in the neighbourhood of the boundary are often very light and granitic and penetrated by some red pegmatites, often accompanied by small veins of nearly pure epidote. In the pegmatite veins on the northern side of the river Driva, breccia-pieces, of gneiss are encountered. These are often augen-gneisses darker than those usually found in the neigbourhood. A layer containing chalcopyrite, purite and hornblende in a gneiss rich in mica also occurs. A little way up the northern slope of the Storhaugen mountain several quite thick amphibolitic layers are contained in the fine-grained gneiss. Long crystals of epidote with a size up to 2 cm are also met with here. On the northern flank of Storhaugen, the boundary flagstone-gneiss is conform and vertical.

On the southern slope of Storhaugen the gneiss borders against basic saussurite gabbro. From this western boundary of the anticline eastwards further the dip that is mostly falling westwards, slackens until it has reached a horizontal level round Ishol bridge. This represents the deepest stratum of this part of the anticline. In the area between the boundary granulite-gneiss at Storløkken farm and Ishol bridge augengneiss prevails with microcline pophyroblasts ranging in size from ½ to 3 centimetres. A little west of the confluxion of the rivers Vindøla and Driva, just at the power-station, a quartz-feldspar dike with some chalcopyrite is found. Chalcopyrite is also an ordinary mineral in pegmatites cutting the gneisses. Just at the electrical power-station there is found a gneiss full of rust-coated slickensides so narrowly spaced that the rust layers lie less than a milimetre apart. Thus the movement occurring during the building of the anticline has been an integral of differential movements, and since the layers lie parallel to the foliation of the gneiss, the movements must either have taken place parallel to primary foliation or, as I think is more reasonable, the structure of the gneiss is formed during the upfolding.

At Ishol bridge the gneiss in the riverside becomes full of small folds and rust patches. The river has here cut a canyon in the rock. In this area there are also some amphibolitic layers. Between this place and the eastern boundary of the basal gneisses, the dominating types are gneiss-granites and augen-gneisses with very few augen. The strike is here NW—SE to N—S, with easterly dip from 20 to 40° increasing towards the boundary. Close to the boundary the gneisses are cut by a lot of quartz schlieren. In this respect they differ from

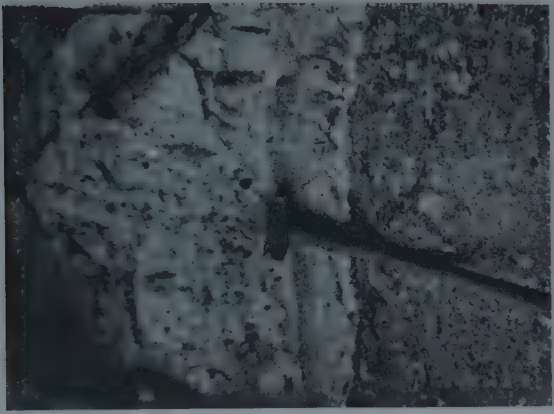


Fig. 4. Red granitic sheet in augen-gneiss W. Lønset.

the gneisses farther south, towards Soløifjell, where the gneisses of the boundary zone exhibit a perfect banking, making them, on weathered surfaces, deceivingly similar to the flagstone in the east. On fresh surfaces, however, the biotite content of the gneisses serves as a mean of discrimination.

From Morken farm the boundary runs southwards towards the northern part of Bjørnetelen. The boundary here forms, together with the adjacent granulite, two small and one large fold in north-westerly direction. From this place the boundary runs southwards to the eastern Soløitjern where another great fold is found. The strike and dip vary in all possible ways round this southern fold. From this place, however, the boundary runs straight E or SE to Stølen farm at the lower end of the river Åmotselven.

From Åmotsdalen farm, the southern boundary of the basal-gneiss complex runs W—NW towards the Mountain Gammelsæterhø, and from Gammelsæterhø W—SW to Tverrfjellet. Further investigations in this westerly direction have not been done.

In the area between Dindalen and the eastern and southern boundary of the gneisses the rocks vary between gneiss-granites and augen-gneisses. Doubtless the augen-gneisses are the main rocks in these parts, and they do not at all differ from the rocks in the northern part of the anticline. Strikes and dips of the rocks are marked on the map. The strike is on all places observed parallel to the boundary, and the dip is always outwards and usually in these parts 30 to 50°.

In the Brattskarven Mountain a great amphibolite layer follows the whole length of the southern hill, and several small amphibolite layers lies in the neighbourhood of the boundary. Between the two Snøfjelltjern's the structure of the gneiss is very unclear with great vortexes. North of the northern Snøfjelltjern a great amphibolite layer lies concordant in the gneiss.

The bottom of Dindalen is filled with loose material and not in a single place the bedrock can be seen, but on the north-western side of the valley the gneisses crop out between Væggsæter and Måsetjern. The strike is almost straight west, thus combining the Lønset-anticline with the Grytvasshaugen-anticline which has been mapped by Holtedahl. The gneisses in this part are often penetrated by finely folded amphibolite layers, and in some places ptygmatic folds occur in the gneiss. Here the gneiss contains a very green hornblende. To the south of hill 1224, the strike gradually changes from ENE, WSW to SW, NE with dip varying from more than 80° to 45° to SE. Farther northwards in the direction of Opdalshø the dip turns more and more in an easterly direction and flattens out to 10°. Especially in these parts the gneiss is full of amphibolite layers. The northern part of this gneiss has a dip of 60—65° northwards and north-eastwards. The northern boundary of the gneiss runs from the southern hill of Opdalshø south-westwards and then westwards to Måsetjern. Here, as usual, the rock on the other side of the boundary is granulitic. This eastern part of the boundary is covered by the loose deposits of Dindalen, but doubtless these gneisses are connected with those south-east of Dindalen.

PETROGRAPHIC INVESTIGATIONS OF THE BASAL GNEISSES

The minerals are the same in all these rocks although their relative abundance varies considerably. The minerals are: quartz, microline, oligoclase, epidote poor in iron (clinozoisite), biotite, and hornblende. In smaller amounts: chlorite and muscovite are found; and as accessories: apatite and titanite. A rather large amount of opake minerals is usually present. These are probably mostly hematite.

I shall here describe a typical sample of a rock of the basal gneisses.

Augen-gneiss rich in biotite (Nedre Hol farm).

This is one of the rocks I used for my determinations of lead and radium. It affords a good illustration of the dark augen-gneisses which are the most common rocks in the gneiss series. The chemical analysis has been made by Mr. B. Bruun in the laboratory of the Mineralogical Institute of the University in Oslo.

SiO_2	63.37	Or.	15.6
TiO_2	0.80	Ab.	32.4
Al_2O_3	16.10	An.	18.5
Fe_2O_3	2.29	Wo.	0.2
FeO	3.77	En.	5.2
MnO	0.11	Hy.	5.7
Mgo	2.10	Il.	1.5
CaO	3.94	Hm.	2.2
Na_2O	3.94	Q.	18.8
K_2O	2.62	S. Sal	86 3 %
P_2O_5	0.04	S. Fem	11.1 »
		Erts	3.7 »

The microscopical mode of this thin-section is not in good accordance with the result obtained by the norm calculation. In other thin-sections from the gneiss series, however, it seems as if the norm and the mode corresponds. In this thin-section the following minerals were observed:

Ca. 25 % dark biotite.
» 5 % hornblende with the following constants: α yellow-green, β grass-green, and γ blue-green, ÷2v ca. 80°, $c: \gamma = 13°$. These are exactly the same constants that are found elsewhere in this district.
» 20 % quartz, strongly undulating.
» 40 % feldspar, one third of which is microcline, the rest being oligoclase with 18 % an. The microcline has small quartz inclusions and seems to be granophyric.
» 10 % zoisite, (+) 2v ca. 50°.

The circumstance that clinozoisite is present shows that not all the lime can go into the plagioclase in solid solution.

It is characteristic that micas of the basal gneisses are bent and partly twisted. This clearly indicates that the upfolding must have taken place after these minerals had been formed. In the granulites, however, I have never found bent micas, although quartz is undulating.

Therefore the micas of the granulite either must have been formed later than those of the basal gneisses, or the granulite with its greater mechanical strength has prevented the bending of its minerals.

THE FLAGSTONES

As seen on the map the flagstones surrounds the basal gneisses on all sides. They can be followed northwards from the quarries by Engan, around the northern part of the anticline to the western part by Tilsethaugen, and on the southern part from Åmotsdalen to Tverrfjellet. They always lies concordant with the gneiss. In numerous places the flagstone is quarried for building purposes, but only at Engan this is done to any greater extent. The stone taken out here is known all over Norway as Opdalsstein.

On the boundary between the gneiss and the granulite by Morken Farm a basal conglomerate is found, which is strongly deformed and difficult to detect. It has a thickness of about 50 metres and can be followed along the boundary to Bjørntelen, where it is squeezed out in the great folds. It reoccurs on the boundary between Bjørntelen and Soløitjern at different places, but at no other places it has been observed; however, the fact that the lower part of the granulite often seems to be richer in quartz than the higher strata may indicate an original conglomerate squeezed and altered beyond recognition.

The character of the conglomerate is seen from Fig. 5. The quartz ellipsoids are here almost pure quartzite, and have resisted the pressure rather well. The average axial relations in the quartzite ellipsoids are about 10: 5: 2. The longest axis lies in the dip, the middle in the strike. The ground mass of the conglomerate contains thin layers of a granite composition, possibly granitic balls squeezed out during the upfolding of the anticline. Owing to their inferior strength they could not stand the pressure as well as did the quartzitic balls.

In the granulite series granitic pegmatites with great amounts of hematite are often found. These are especially abundant in the granulite between Lønsetmoen and Tilset. Here patches of hematite up to 10 centimetres occur in great numbers. At other places, for instance in the neighbourhood of Furunes farm, between Ålbu and Lønset, the feldspar in the granulite has grown to greater porphyro-

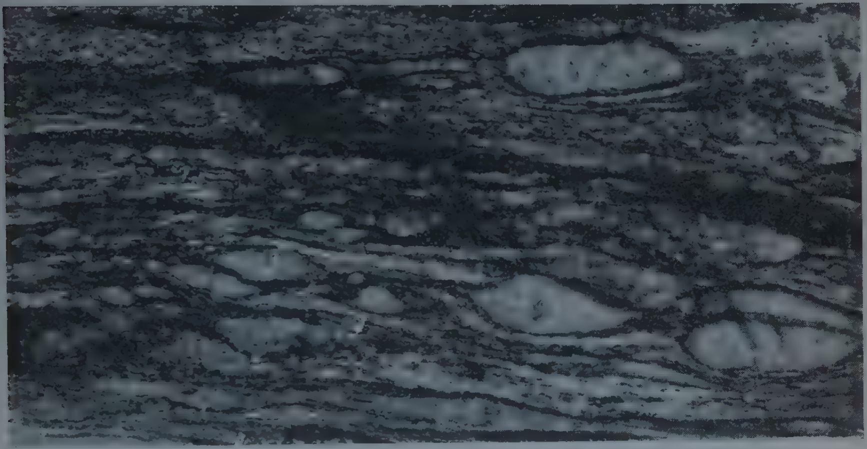


Fig. 5. The conglomerate by Morken farm, with quartzitic balls and granitic layers in the groundmass. ½ × nat. size.

blasts, and the rock may here be called a muscovite augen-gneiss. In the southern part, north of Stølensæter in Åmotsdalen, the minerals in the granulite are again unusually large, and the rock may perhaps more appropriately be called muscovite gneiss. On the whole, it is often difficult to distinguish between gneiss and granulite in this southern area. As shown on the map, the dip is here mostly to the south. Between Hammerbekken and Urvassbekken, north-west of Hellausæter, the banking is horizontal. South of Hammerbekktjern, it has a northerly dip of 45°. The smaller flagstone series south of Gråhø and north of Veggvatn, seem to be inclusions or infoldings of some kind. The tectonic is here not quite clear. By Soløibekken, between Soløitjern and the Tronna river, sharp folds occur in the granulite, structures that seem to be secondary schistosities, also appear.

PETPOGRAPHIC INVESTIGATIONS OF THE GRANULITES (FLAGSTONES)

Barth (II) has described the development of the sparagmite series from east to west, i. e. from unmetamorphic sparagmite in Engerdalen, through more metamorphic phases in the northern part of Østerdalen and Gudbrandsdalen, to the highly metamorphic granulites in the Opdal district.

Characteristic features are that microcline which is the only feldspar in the unmetamorphic sparagmite slowly disappears, giving way to ortoclase and acid plagio-clases. At the same time the feldspar partly hydrolyses and muscovite and then epidote and biotite in smaller amounts appear. I shall here take a typical specimen of the granulites in the Lønset anticline. The sample has been collected by professor Barth, and the thin-section is called "Granulite W. Lønset O I 11". It contains:

Ca. 30 % quartz somewhat undulous.
» 25 % mica minerals, nearly all muscovite in sub-parallel arangement, with some biotite, haphazardly orientated.
» 45 % feldspat, about 75 % microcline, and ca. 25 % oligoclase with 19 % an. Some of the K-feldspar grains are somewhat corroded from the edges, and in something that seems to be old perthites, younger muscovite appears. A few small hornblende crystals are also present. With the exception of part of the K-feldspars, all the minerals seem to have been formed by re-crystallization. The K-feldspars, however, seem to be of clastic origin.

This specimen is representative for most of the flagstone and granulite in the series, although this is the only thin-section where the curious K-feldspar has been observed. Especially in the southern part and in the smaller granulite inclusions south of Gråhø and north of Væggvatn, all minerals must have re-crystallized. Here the muscovite crystals attain a size of a couple of millimetres.

THE SAUSSURITE GABBROS OF GRÅHØ

As seen from the map these are found from Øyasæter in the east to Opdalshø in the west. They have sharp boundaries running from east to west. In the south they border on an augen-gneiss which seems to be a contact product between the gabbros and the granulite. To the north they cut into the granulite by a number of branches; especially at Storhaugen the boundary is very irregular. On the south hill of Storhaugen, north of Uffsæter, Ishoelsæter, and Holsæter, small quartz inclusions up to 1 centimetre in diametre are found in the rocks.

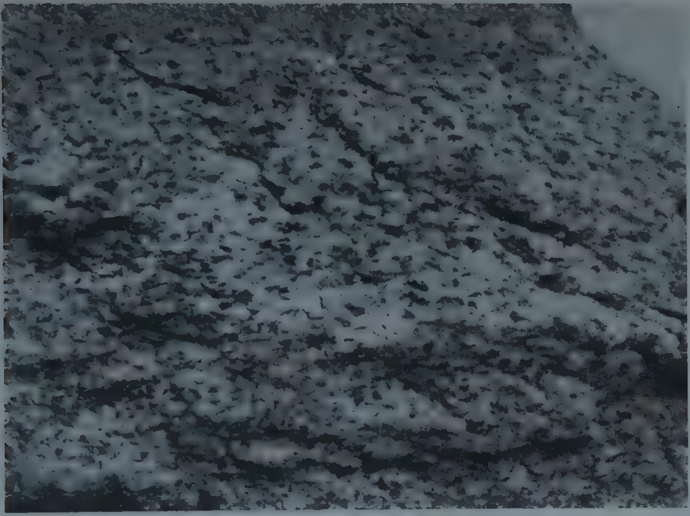


Fig. 6. Inmelted gneissgranite in the saussurite-gabbro of Gråhø. ½ × nat. size.

In the central part of the saussurite gabbro the rock is coarse-crystalline with mineral grains up to 1 centimetre. At Storhaugen the peripheral parts of the gabbro seem to have resorbed great amounts of granulite, and seem to change into granulite by degrees, but there is no augen-gneiss here. No real contact between the granulite and the gabbro is found here as the top of Storhaugen is covered by loose material. Most of the gabbro is without any foliation, but especially south of Storhaugen it is possible to measure strike and dip. There may seem to be a slight discordance between the foliation of the gabbro and that of the granulite. As mentioned before, no real contact was found, and nothing can be definitively said about this.

North of Gråhø mountain several inclusions of gneiss granite occur in the gabbro. The inclusions exhibit thick transitional zones, the outer part of the inclusions thus being fully absorbed. The central parts, however, have kept their primary character. An inclusion of conglomerate is also found and in spite of a rather strong resorption, the conglomerate balls appear rather intact, showing no obvious sign of deformation. Most of the balls are granitic and quartzitic with sizes up to three centimetres in diametre. One may also come across gabbro so coarsely crystalline that it must be called gabbro pegmatites. The granulite north of the gabbro strikes parallel to the boundaries and dips steeply from 70° towards the gabbro to 80° from the gabbro. Again no transitional zone of augen-gneiss can be seen, but the outermost part of the gabbro seems to have resorbed granulite as it is lighter near the boundary and also contains a small amount of quartz.

PETROGRAPHIC INVESTIGATIONS OF THE SAUSSURITE GABBRO OF GRÅHØ

Amphibolite 40 Storhaug.

This rock is not quite typical of the Gråhø saussurite gabbro, but has been chosen here because it clearly shows that the gabbro has been exposed to metamorphism.

Analysis of Amphibolite 40.

SiO_2	57.02 %	Or.	25.9 %
TiO_2	0.98 »	Ab.	27.5 »
Al_2O_3	16.93 »	An.	18.6 »
Fe_2O_3	3.61 »	Q.	7.2 »
FeO	5.71 »	Wo.	5.8 »
MnO	0.16 »	En.	5.3 »
MgO	2.12 »	Hy.	6.7 »
CaO	4.68 »	Ro.	0.3 »
Na_2O	3.25 »	Il.	1.9 »
K_2O	4.36 »	Hm.	2.2 »
P_2O_5	0.31 »	Ap.	0.6 »
H_2O ±	1.20 »		
Sum	100.33 %		

The normative mineral composition corresponds in no way to that really found in the rock. In thin-section the following minerals are found:

Ca. 50 % hornblende, α yellow-green, β grass-green, γ blue-green, $\div 2v$ ca. 80° $c: \gamma = 14°$. The hornblende crystals are in some places strongly bent. Other minerals are:
» 20 % biotite, in sub-parallel orientation.
» 20 % zoned plagioclase, with an average composition of 35 % an. The feldspar is slightly kaolinized.
» 5 % epidote, light-coloured (clinozoisite).
» 5 % quartz, slightly undulating some small garnets.

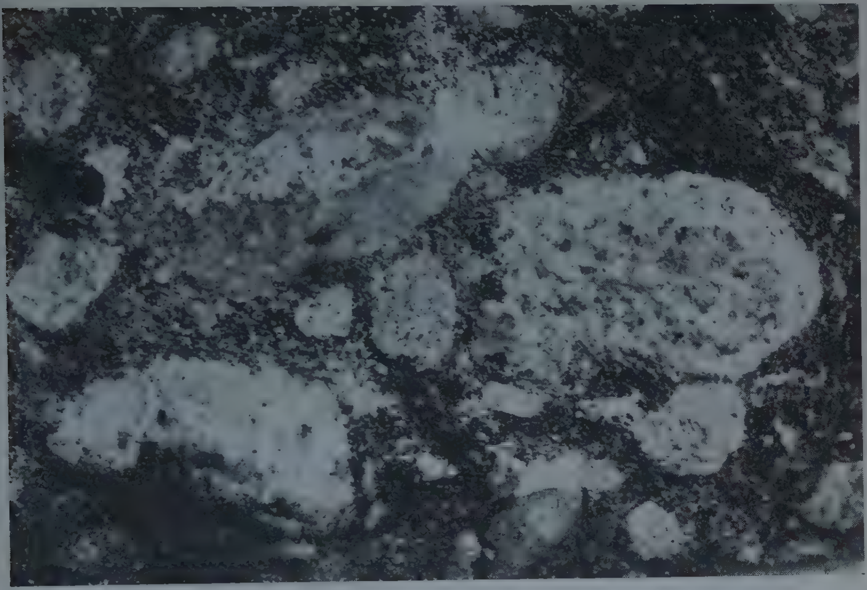


Fig. 7. Inmelted conglomerate in the saussurite-gabbro of Gråhø. Nat. size.

This mineral assemblage seems to indicate a relatively low temperature during the metamorphism, and the temperature that Barth (II) assumes for the metamorphism and the upfolding of the anticline, viz. 3 to 400 degrees centigrade, is perhaps a little too high, as undulating quartz normally would re-crystallize at this temperature. It is possible, however, that the undulance of the quartz may have been caused at a later stage.

Saussurite Gabbro n. 39/40 W. Storhaugen.

In thin-section the following minerals are found:
Ca. 50 % hornblende of the ordinary type found in the gabbro masses.
» 50 % saussuritized plagioclase.
Consequently it is a typical saussurite gabbro.

Amygdaloid 28 South Hill of Storhaug.

This rock resembles a conglomerate, soaked in a ground mass of diabase character. An analysis of the pure groundmass shows:

SiO_2	51.96 %
Al_2O_3 TiO_2	18.24 »
Fe_2O_3	3.35 »
FeO	7.08 »
CaO	8.22 »
MgO	5.24 »
Na_2O	2.91 »
K_2O	1.71 »
$H_2O \pm$	n. d »
Sum	98.71 %

$$\frac{Al_2O_3}{Na_2O + K_2O + CaO} : 0.82$$

Large grains of quartz and sharp-edged feldspar crystals (up to 1.5 cm in length and 0.5 cm in width) occur in the ground mass. This resembles finely grained gabbro or diabase. In thin-section the following minerals are found:

Quartz in large round grains with a diametre of 2—10 mm. The quartz shows fissures running-sub-parallel in the different grains. The fissures occur in two typical directions, mutually perpendicular. The quartz grains are also sporadically present in the ground mass.

The feldspar present consists of two typical generations. First, we have the great sharp-edged crystals as distinct pheno-crystals. This feldspar is undergoing full alteration, as it is made up of small crystals about 1/100 millimetre in length. Because of their smallness it is impossible to determine them optically, but as the refraction index is definitely higher than that of the Canada balsam, it is probable that they must be plagioclase. Besides plagioclase the aggregate contains clinozoisite. The feldspar of the ground mass is an andesine an. 33 %. Biotite and hornblende are also contained in the ground mass. Structural features indicate that we have to do with a slightly metamorphic quartz amygdaloid.

Schistous Amphibolite 39 Storhaug.

This rock is almost identical with amphibolite 40, but has been taken a little farther from the boundary. It grades into the amphibolite 40 as well as into amygdaloid 28.

The main feldspar in this rock is a zoned plagioclase varying in composition from 36 % an. in the centre to 28 % an. in the periphery. Potash feldspar is probably not present. Quartz which is found in fairly large amounts, shows undulating extinction, and is two-axial. 40 % hornblende with the optical constants 2v ca. 80° α yellow-green, β pure green, γ blue-green, angle c: $\gamma = 13°$.

Small amounts of light epidote and bent biotite are among the other minerals present.

This rock has been taken only 30 to 40 metres from typical basal gneiss. The strongly undulating quartz and the bent micas show that it has taken part in the Caledonian movements. The zoned plagioclase, on the other hand, shows that it has not been under the influence of the thermo-dynamical conditions that gave rise to the uniform oligoclase with 16 to 20 % an. which occurs in all the typical basal gneisses in spite of compositional variations of the containing rock. These circumstances indicate that the saussurite gabbros of Gråhø are younger than the sparagmite and older than the Caledonian movements. It seems probable they belong to the Trondheimsfelt saussurite gabbros, and should hence be of Cambro-Silurian age. I have discussed the matter with professor Barth, who also thinks this a reasonable assumption.

The inclusions of gneiss granite and of conglomerate in the Gråhø saussurite gabbro evidently prove that the gabbro was intruded into the basal gneisses and the sparagmite series, and that it has not been placed in the present position by any tectonic movement. The gneiss inclusions with their distinct banking have the same character as the gneiss granites in the basal gneisses.

The Inclusions.

The microscope shows the gneiss inclusions to contain the following minerals:

Ca.	10 %	microline.
»	20 »	basic oligoclase.
»	10 »	epidote.
»	20 »	hornblende.
»	20 »	biotite.
»	20 »	quartz, slightly undulating.

All the minerals seem to be re-crystallized, but since the structure of the gneiss-granite is well preserved, they cannot have been fully melted.

The conglomerate inclusions consist of balls of granite and quartzite, and show no visible signs of having been pressed. The quartzite balls consist of very pure re-crystallized quartz, not undulating, and showing only few cracks. It borders sharply against the ground mass. The ground mass consists chiefly of small plagioclase crytals, biotite, epidote, and a little green hornblende. The granitic balls which mostly are 1 to 4 cm in diametre, consist of feldspar grains strongly altered to muscovite, and plagioclase with myrmecitic quartz. The edges are quite corroded and interwoven with biotite. Other minerals are epidote, basic oligoclase, feldspar, and quartz. In the ground mass there are furthermore larger feldspar fragments, which seem to be altered microcline. This conglomerate which in all probability is the same as that found as basal conglomerate in the granulite series at Bjørntelen, shows no signs of stress. This indicates that the gabbro at the time of its intrusion met with, and scattered, an undeformed conglomerate, fragments of which it incorporated, and later, by transforming the orogenic stress forces to hydrostatic pressure, protected the conglomerate from deformation. Sederholm (III) has shown something similar to this to have occurred at Bockholm in the Åland Islands.

The gneiss inclusions, however, show a remarkable foliation which proves that the gneiss already had this structure at the time when the conglomerate was broken up by the gabbro, i. e. before the Caledonian movements.

THE GABBROIC VEINS AND THE AMPHIBOLITIC LAYERS IN THE GNEISSES

As already mentioned in the description of the basal gneisses, a number of thinner and thicker basic layers are found in the gneiss series. Some of these may perhaps be due to primary differentiation, but others are certainly younger diabases cutting the gneiss. A particularly good specimen is found on the road from Ratet to Ishol bridge. A dark diabase cuts into the light gneiss granite, and as shown in Fig. 10, the outermost parts of the diabase have resorbed gneiss granite to such a great extent that it has retained the structure of the diabase. The transitional zone is about 10 cm thick, and I am inclined to believe that these gabbroic veins belong to the Gråhø gabbro as hypabasic phases. Anything definite about this cannot be stated, as I have never found any diabase going out from the gabbro massif into the gneiss.

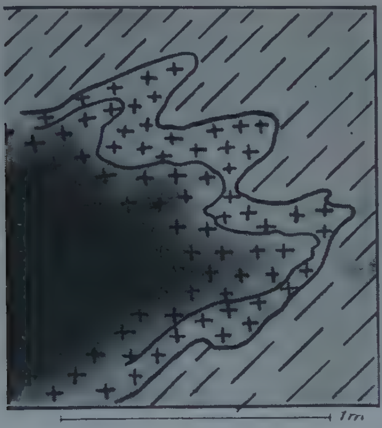


Fig. 8. Basic vein ending in gneissgranite, with transition zone.

THE GREEN SCHISTS

On the part of the map where I have worked, no large amount of green schist is found. The only place of occurrence is west of Tilset and Tilsethaugen. Holtedahl (I) has dealt with these rocks in the paper cited. In the green schist west of Tilset and north of Bekken farm a couple of prospect-pits for copper are to be found. The green schist round the copper ore is hydratized to a talcum schist. This consists of some talcum, very much chlorite, a little calcite and opaque minerals, most of them being pyrite.

This green schist stratum lies in a syncline the folding axis of which dips northwards ca. 15°, so that it disappears into the air west of Tilsethaugen, and the underlying granulite appears. As Holtedahl (I) has suggested, this green schist is Cambro-Silurian and belongs to the green schist of the Trondheim area. It may thus correspond to the more or less volcanic phases of the Gråhø gabbro, or of similar rocks. In the green schist in the neighbourhood of the copper ore, dolomite crystals with an edge-length up to 3—4 cm, are found. This dolomite is certainly a secondary mineral.

East of Hullberget farm, in the western part of the green schist area, the green schist passes over into augen-gneiss. How this augen-gneiss is to be interpreted is not yet quite clear, but I am inclined to think that it is a meta-somatically changed green schist. A rock resembling this augen-gneiss is found on Hornet mountain, north-west of Driva railway station, and also between Engan station and Rise. The augen-gneiss is here very coars-crystalline, and lies as an infolding in the granulite. This is the rock that Carstens (IV) has called a rapakivi. More thorough investigations on this point are later to be carried out.

CONCLUSIONS

Both the basal gneisses and the flagstones exhibit good foliation and it is a striking fact that full conformity exists between the two rocks. Strike and dip can be measured very exactly. As a rule, the boundaries are very sharp and can easily be observed, on account of the gneisses always holding large amounts of biotite, whereas this mineral is either wholly lacking or is present only in small quantities in the granulites. But only in the eastern part of Drivdalen sharp boundaries are the rule. According to Barth (II) the boundary is more transitional in other parts.

Distinct boundaries between the basal gneisses and the flagstone are *in principle* not in discordance with the conception that the gneiss as well as the flagstone are of sedimentary origin. Neither does this exclude the idea that the sedimentary rocks through a strong metamorphism or migmatization were transformed to the rocks now present.

Obviously not all layers in a sedimentary series must necessarily have the same chemical composition. That more psamitic layers alternate with more pelitic or chalky layers is often the case. Exposed to migmatization the different layers would of course react differently.

The conglomerate on the eastern boundary shows, however, that the assumption of a direct connection between the underlying gneisses and the granulite series presupposes that the sedimentation has taken place in a particular manner: first a sediment, rich in lime and aluminium must have formed after which an elevation of the ground gave birth to the conglomerate and the sparagmite above. If, however, the gneiss and the granulite form one sedimentary series, as contended by Holtedahl, a sharp boundary between the deeper high-metamorphic layers (the basal gneisses) and the overlying less metamorphic layers (the granulites) would seem unlikely. Moreover, that this division in degree of metamorphism should coincide exactly with the conglomerate zone, seems improbable. Barth (II), however, has observed foggy boundaries between granulite and gneiss, but since his observations were made farther west, where the temperature may have been higher and the pressure stronger, they do not invalidate the present conclusions.

In the Lønset anticline the granulite and the gneiss lie so close together that there cannot possibly have been any difference in the conditions during a supposed Caledonian migmatization. Therefore, if the temperature was sufficiently high, an impure sandstone (a sparagmite) would leave a solid residue of quartzitic composition, as shown by Eskola (V).

The gabbro area which is post-Sparagmitian and pre-Caledonian contains, as mentioned, zoned plagioclase a few metres from the basal gneiss. This makes it highly improbable that a Caledonian migmatization alone created the very uniform plagioclase in the basal gneisses, as the thermo-dynamic conditions cannot have been very different in the two rocks.

For the reasons mentioned, I regard it almost certain that the basal gneisses represent the basement on which first the conglomerate and later the flagstone series were sedimented.

The remarkable conformity between the basal gneisses and the flagstone seems to indicate a closer connection between these two rocks. The forces, however, which have been sufficient to squeeze out the conglomerate balls to the flat lenses now found, may also have been sufficient to give the gneiss a new foliation parallel to these lenses. In this case a pseudo-conformity would be the result, and as the strike varies considerably in the gneiss, it would be difficult to discover whether the conformity is false or not. A fact which would seem to indicate that the foliation now found in the gneiss is a secondary phenomenon, is that ptygmatic folds are found in the gneiss. In the granulite, however, I have never found this kind of structure. To be able to state with certainty whether or not, a primary structure is present in the gneiss, a microscopic structure analysis is necessary. This analysis is later to be carried out.

A constant feature in the rocks belonging to the basal gneiss complex, is, as already mentioned, the very uniform composition of the plagioclases with an anorthite contents of 18 %. This is also the case when the normative feldspar is richer in anorthite, the additional calcium contents in this case being present in the form of epidote and partly in the form of hornblende.

In none of the samples of basal gneisses investigated, an appreciable excess of alumina is found. If, however, the sparagmites and the granulites are investigated in this manner, an excess of Al_2O_3 and hence normative corund is found. This too does not harmony very well with the conception that the basal gneisses are deeper deposits of the same sedimentary series, as the conditions of metamorphism must have been almost the same in gneiss and granulite. Still less this accords with the idea that the gneiss should correspond to layers, richer in clay. If, however, the gneiss is an old ichor-gneiss or an originally igneous rock, the absence of an alumina excess finds its natural explanation.

Some of the analyses in Barth's publication (II) together with some of my own analyses from the same area are referred to below.

Analysis of Sparagmite and Granulite.

	2	3	4	5	6	7	8
SiO_2	80.89	83.47	89.16	72.17	74.66	77.79	76.34
TiO_2	0.40	0.33	0.11	0.48	0.76	0.29	0.41
Al_2O_3	7.57	8.17	5.21	13.74	11.45	12.39	11.45
Fe_2O_3	2.90	1.61	1.25	2.76	4.32	1.90	3.00
FeO	1.30	0.81	0.43	0.38	0.44	0.52	0.30
MnO	—	sp.	sp.	sp.	0.03	sp.	—
MgO	0.04	0.03	sp.	1.04	1.04	0.02	1.07
CaO	0.04	0.10	0.04	0.31	0.09	0.06	0.16
Na_2O	0.63	1.12	1.02	1.33	2.11	3.86	2.17
K_2O	4.75	3.78	2.62	5.98	3.87	2.21	4.57
H_2O	1.11	0.70	8.26	1.47	0.99	0.89	0.95
P_2O_5	–	sp.	sp.	0.05	0.03	0.02	—
$\frac{Al_2O_3}{K_2O + Na_2O + CaO}$	1.29	1.15	1.14	1.49	1.46	1.40	1.22

2. Sparagmite Borveggen, Engerdalen.
3. Sparagmite N. Fron.
4. Sparagmite N. Fron.
5. Sparagmite Knappen Atnabru.
6. Granulite Svorunda bru Opdal.
7. Granulite W. Svorunda bru Opdal.
8. Granulite Between Sliper and Lønset.

Analyses of Rocks from the Basal Gneiss.

	2	3	R. G	B. Ø.
SiO_2	65.97	61.07	76.14	63.37
TiO_2	0.52	0.96	—	0.80
Al_2O_3	16.67	16.61	13.17	16.10
Fe_2O_3	3.58	3.21	0.41	2.29
FeO	0.82	2.65	0.58	3.77
MnO	—	0.03	0.10	0.11
MgO	1.20	1.67	0.03	2.10
CaO	3.35	4.95	0.82	3.94
Na_2O	3.17	3.79	3.05	3.94
K_2O	3.91	3.61	5.28	2.62
H_2O	0.79	0.97	0.40	—
P_2O_5	0.10	0.25	—	0.04
$\frac{Al_2O_3}{K_2O + Na_2O + CaO}$	1.06	0.86	1.06	0.97

2. Basal-gneiss Bø farm.
3. Basal gneiss Hol farm.
R. G. Red gneiss granite, (basal gneiss) Lønsetmoen.
B. Ø. Augen gneiss rich in biotite, Nedre Hol farm.

The analyses, designated with numbers, have been taken from Barth's publication (II). The analyses designated with R. G. and B. Ø. are new analyses, carried out for me by Mr. B. Bruun.

Later analyses, carried out by Mr. B. Bruun for Professor Barth, as yet unpublished, show that the Al_2O_3 excess in the granulite decreases considerably in the western part of the district. There is, however, as shown here in the Lønset anticline, a considerable difference between the granulites and the gneisses.

Oslo Dec. 1940.

Universitetets mineralogiske institutt.

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STUDIES ON TRILOBITE MORPHOLOGY

PART II.

THE LARVAL DEVELOPMENT, THE SEGMENTATION AND THE SUTURES, AND THEIR BEARING ON TRILOBITE CLASSIFICATION

BY

LEIF STØRMER

WITH 2 PLATES AND 19 FIGURES IN THE TEXT

To the Memory of

PROFESSOR DR. W. C. BRØGGER

Abstract. The present studies on trilobite morphology succeed a first part dealing with the thoracic appendages and their phylogenetic significance. In preparing a second part on the cephalic appendages and the affinities of trilobites, it became obvious that these subjects could not be satisfactorily treated without a detailed study of the larval development. Consequently I have carried out an investigation of the literature available, and have reexamined important ontogenetic series preserved in the Paleontological Museum of the University in Oslo. The studies have suggested new conceptions of the structure and origin of some of the more important trilobite characters. For this reason the present research on the larval development is published before the description of the cephalic appendages and the general discussion of the trilobite affinities.

The ontogenetic studies have indicated a new division of the earliest larval period. In spite of considerable difference in the structure of the protaspis, it seems possible to homologize the larval characters in the Olenellidae (=Mesonacidae) with those in the typical opisthoparian and proparian trilobites. The protaspis of the Olenellidae has a well-developed preantennal segment, the dorsal development of which is considerably delayed in the ontogeny of the members of the other groups. The primitive segmentation of the protaspis is discussed and the existence of merely primary somites in the cephalon is emphasized. The oblique direction of the cephalic segments exposed in the primitive larvæ have led to the assumption that the transverse suture between the cephalon and the transitory pygidium, and later also between the thoracic segments, are secondary joints or hinge-lines crossing the primary segmentary borders indicated in the pleural furrows. The ontogeny also suggests a new interpretation of the cephalic sutures which have been of primary importance to the current classification of trilobites. It seems possible to derive the facial suture of the Proparia and Opisthoparia from the primary marginal suture apparently present in all protaspis, and maintained in the adults of the Olenellidae and probably the Hypoparia. The Olenellidae form apparently a primitive, more or less ancestral group of trilobites which might be distinguished as a special Order for which Swinnerton's name Protoparia is suggested. The differentiation of the Class Trilobita into several Orders, according to the Salter-Beecher system, seems largely to be due to the arrested development of the preantennal segment, a phenomenon here interpreted as due to partial neoteny or merostasis. The arrested development seems at the same time to illustrate another evolutionary principle according to which new morphological characters first appear in the early ontogenetic stages.

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INTRODUCTION

The larval development of trilobites early attracted the attention of students in paleontology and zoology. Many writers have pointed out the phylogenetic importance of the larva of these old and primitive arthropods. There has, however, been some divergence of opinion as to the degree of the phylogenetic value of the larva. While certain workers have meant to trace detailed phylogenetic characteristics

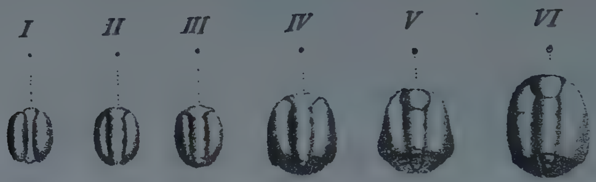


Fig. 1. Early larvæ of *Liostracus* from the Middle Cambrian of Øxna, Norway. 15×. I—II = anaprotaspides. III—VI = metaprotaspides. After Brøgger 1875 pl. 25 fig. I—VI.

through all the different larval stages, others have referred the larval features to chiefly external influences and thus representing larval adaptions only. As pointed out by Raw, the truth lies somewhere between and it seems largely possible to identify both kinds of characters.

Classical in the research on trilobite ontogeny are the works of Barrande published in his great memoir from 1852. It was the merit of Barrande to give, for the first time, a detailed description of the larval development of a trilobite. A considerable number of larval stages were figured and described of the Cambrian species *Sao hirsuta* Barrande, but in addition to this form the ontogeny of several other genera such as *Agnostus*, *Cryptolithus*, and *Dalmanitina* was elucidated. Barrande found that the larval development took place along different lines which might be confined provisionally to four divisions. Only two of these divisions he thought would remain as permanent groups. The first includes forms in which the pygidium is not differentiated (*Sao*-type) and the other comprises forms with a distinct pygidium (*Trinucleus* and *Agnostus*-type). Barrande's divisions are based on late Protaspid stages and evidently include forms of remote relationship and therefore are of minor value according to our present knowledge.

In 1875 Brøgger presented a valuable illustration of the earliest larval stages of *Liostracus linnarssoni* Brøgger, from the Middle Cambrian of Norway. As shown in text-fig. 1 he describes a fairly complete series comprising earlier protaspides than those described by Barrande.

The American Paleontologist Ford (1877) described the first larval stages of the Lower Cambrian Olenellidae. One of his figures is depicted in text-fig. 3. His first descriptions were followed by numerous important illustrations by Walcott. Especially in his extensive monograph on "Olenellus and other genera of the Mesonacidae" (1910), Walcott throws new light on the primitive protaspis of this group. Meanwhile Matthew (1884, 1887) had described the early larvæ of Middle Cambrian species, and Bernard (1894) had discussed the protaspis in connection with the cephalic segmentation of the trilobites.

The first special treatment and general discussion of the trilobite larva were carried out by Beecher who published his results in 1895. Beecher points out that the earliest larvæ of all trilobites form small discoid bodies in which the cephalic portion greatly predominates. In spite of the considerable specific variation he was able to demonstrate a common type of larva which he called the protaspis and which he compared with the nauplius of the Crustacea. In his later paper (1897, p. 99) he gives the following definition of the protaspis:

"Dorsal shield minute, not more than 0.4—1.0 mm in length; circular or ovate in form; axis distinct, more or less strongly annulated, limited by longitudinal grooves; head portion predominating; axis of cranidium with five annulations; abdominal portion usually less than one-third the length of the shield; axis with from one to several annulations; pleural portion smooth or grooved; eyes when present anterior, marginal or submarginal; free cheeks, when visible, narrow and marginal."

Beecher was aware that the trilobites possessed several succeeding Protaspid stages, and having in mind the conditions in the Crustacea, he suggested the presence of an anaprotaspis, metaprotaspis, and paraprotaspis representing succeeding stages in the early larval development. For the later larval period he introduces the terms nepionic, neantic, ephebic, and gerontic. All these names have more or less been used by later authors, but the terms were not exactly defined.

All the protaspides figured by Beecher belong, however, to more advanced stages in which postcephalic segments were developed. On account of the presence of intramarginal eyes and well-developed cheeks in the first larvæ of the Olenellidae, he did not recognize these as early protaspides. He demonstrated in several trilobite larvæ the migration of the lateral eyes from the anterior margin backwards to their intramarginal position in the adult. He claimed also that the eyes had migrated from the ventral side forward to the margin, but no direct evidence was presented to support this assumption. It is the merit of Beecher to have described in detail the structures of the protaspis, and to have attempted to arrive at a natural classification based on the ontogenetic and phylogenetic development.

Lindström (1901) stressed the phylogenetic importance of the characters expressed during the larval development. Particularly the development of the eye ridges was regarded as being of primary value in deciding the phylogenetic relationship.

Like Lindström, more recent authors such as Swinnerton (1915, 1919) and Raymond (1917) paid more attention to the young larvæ of the Olenellidae which had been more neglected by Beecher and had become better known through works of Walcott (1910) and Kiær (1916).

During more recent years larval stages of trilobites have been described by numerous scientists, but the descriptions mostly deal with singular finds presenting little general information on the ontogeny. A more complete list of the descriptions is given by Raw (1925) and many of the papers are mentioned in the special part of the present paper. Among these papers might be mentioned the description of the larvæ of *Peltura scarabaeoides* (Wahlenberg) by Poulsen. Poulsen (1923, 1927) was able to demonstrate that during the larval development *Peltura* and other opisthoparian trilobites passed through early post-protaspid stages in which a proparian suture was present. This seemed to indicate that the Opisthoparia evolved from proparian ancestors.

In an important discussion on the zoological position and classification of the Trilobita, Warburg (1925) considers the knowledge of the trilobite ontogeny and tries to homologize the rather different structures in the larvæ of the Olenellidae and typical Opisthoparia. From the knowledge available and from new studies on the ontogeny of *Liostracus*, Warburg arrived at the conclusion that the larvæ of both groups possessed a "larval ridge" at the frontal border of the protaspis. More recent studies, however, have shown the structures to be more complicated. Thus Strand (1927) was able to demonstrate the presence of ridges in front of the eye-ridges in the larva of *Olenus*.

A valuable contribution to our knowledge of the trilobite ontogeny has been given by Raw (1925, 1927) in his paper on the larval development of *Leptoplastus*. Only post-protaspid stages are known, but Raw gives a detailed account of previous research, and presents the results of personal studies on foreign material. He is especially interested in the ontogenetic and phylogenetic development of the cephalic spines and introduces a new hypothesis on the origin of the spines, a hypothesis, however, which has met with considerable criticism as mentioned below. Raw introduces a new division of the post-protaspid larval development. He replaces the names of Beecher by the terms Meraspid and Holaspid Periods of growth, the latter comprising the stages after the complete number of thoracic segments is attained.

Stubblefield (1926) presents an important description of the larval development of the small and peculiar trilobite *Shumardia*. He demonstrated the subterminal origin of new segments during the growth. New studies on the larval development of *Paradoxides* were carried out by Šuf (1926) in addition to previous descriptions by Barrande and Raymond (1914).

More recently several papers have been published which have proved to be of considerable interest in revealing a series of early protaspides previously little known in trilobites. Poulsen (1932) describes very early protaspides of Olenellidae from Greenland, and Endo (1935 a, 1935 b) illustrates numerous larvæ of an opisthoparian trilobite from Manchukuo. In spite of repeated descriptions of early *Paradoxides* larvæ, the protaspis of this genus remained little known until Westergård (1936) describes a very interesting series including both early and late protaspides. The presence of eyes and facial sutures in the protaspis of Cambrian trilobites was claimed by Lalicker (1938), but it seems possible that a certain misinterpretation of the larval structures might have taken place.

Special attention has recently been drawn to the trilobite ontogeny by the arthropod studies of the zoologists Ivanov (1933), Shulze (1935), and Snodgrass (1938), by whom the trilobite is compared with the primitive Chelicerata.

In the present paper I have tried to recapitulate and combine our present knowledge on trilobite ontogeny, and attempted to arrive at a general conception on the structures of the trilobite larva. As far as possible I have tried to complete the previous knowledge by new research. More careful studies have been carried out on Norwegian material of *Holmia*, *Liostracus*, and *Olenus* previously described by Kiær, Brøgger, and Strand. By means of more satisfactory technical equipment it has become possible to demonstrate new details in the early larvæ of these genera. I wish to express my best thanks to Dr. T. Strand for placing at my disposal the interesting material of

Olenus collected by him. I am also indepted to Dr. A. H. Westergård for valuable information concerning the early larvæ of *Paradoxides.* In preparing the illustrations of the present paper I have had valuable assistance by Mrs. Kirsten Arneberg, Miss Bergljot Mauritz, and Miss Lily Monsen.

TERMINOLOGY

It might prove useful to discuss and define the different terms applied in the following description of the larval stages. Following Raw the larval development of the trilobites comprises the Protaspid, Meraspid, and Holaspid Period of growth. The growth takes place through a great number of ecdysis. In the smallest larvæ the stages might be separated by size such as indicated in *Tretaspis* (Størmer 1930, p. 59), but normally the morphological structures form the base of classification.

The Protaspid Period includes all the earliest stages from the hatching to the appearance of the first transverse suture dividing the dorsal shell into two separate shields, the cephalon and the transitory pygidium (see below). In the first part of the Protaspid Period the number of segments seems to be constant, but in the later part postcephalic segments are gradually added. A division of the Protaspid Period is therefore suggested. The Anaprotaspid Period comprises the earliest stages in which the axis has only five segments, and the Metaprotaspid Period includes the later stages in which new segments are added beyond those present in the anaprotaspis. A number of stages or Degrees might be distinguished.

The different stages of the Meraspid Period are designated as Degree $0 — (n \div 1)$, n being the number of free thoracic segments. Degree 0 represents the stage in which the cephalon and transitory pygidium are separated, but no thoracic segment developed. It is probable that extra moultings take place within one Degree, and in this case sub-stages, e. g. Degree 2 a, b, c, might be distinguished. New segments might also be formed in the pygidium after the Holaspid Period is reached.

As shown in text-fig. 2, the terms distinguishing the morphological characters of the protaspis largely correspond to those previously applied. The dorsal shield of the protaspis includes a series of succeeding segments which are easily distinguished especially in the Lower Cambrian form (2 a). It seems natural to base the terminology

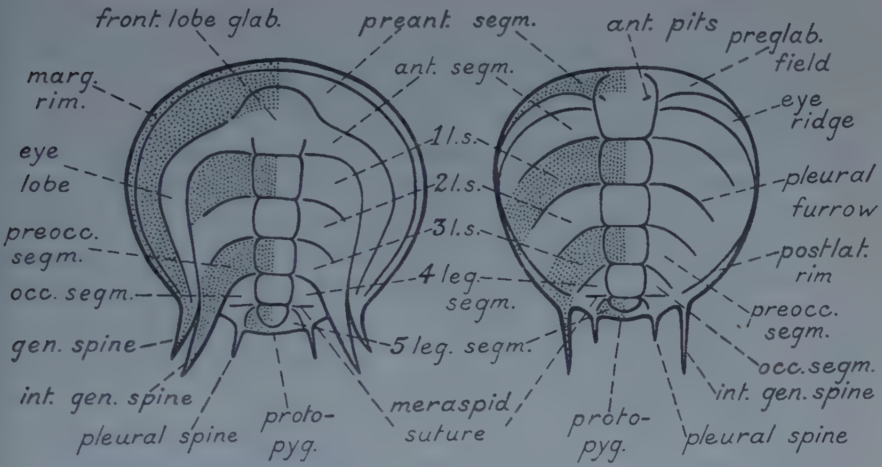


Fig. 2. Diagrammatic drawing of protaspis (metaprotaspis Degree 1) of Olenellidae and Olenidae (Protoparia and Opisthoparia). Every second segment is shaded in order to demonstrate the homology of the segments in the two protaspides.

to a great extent on this primary segmentation. The lower surface of the protaspis is unknown, but we might assume that a labrum or hypostoma was present in front of the mouth, and this plate was attached to a doublure (or rostrum if forming a separate plate). On the dorsal surface the segments are more or less concentrically arranged. The study of the cephalic appendages and their relation to the glabellar lobes and furrows in the protaspis, has indicated that of the five pairs of appendages the antennæ belong to the frontal lobe, and the four pairs of legs to the four posterior lobes. The legs were apparently attached to muscles leading from apodems formed by the transverse furrows in front or in the frontal portion of each lobe. Concerning the frontal lobe, the furrows serving as apodems for the antennæ appear at a later stage and might be termed antennuary pits such as in the Trinucleidae. Since the antennæ belong to the segment forming the frontal lobe in the anaprotaspis, the segment in front, the preglabellar area, might be called the preantennal segment. In the previous literature it has been referred to as the ocular segment (eye segment of Henriksen), but, although this might prove to be correct, the protaspis does not demonstrate whether the rudimentary visual surface belongs to the frontal segment (it belongs to the free cheek in specimens with dorsal facial suture) or to the palpebral lobes belonging to the following segment. The name suggested seems more neutral.

The antennal segment comprises the frontal lobe (or the major portion of it), the eye ridges and the rest of the segment behind them as well as the palpebral lobes. The term antennal segment has probably been avoided by several writers for the reason that they believed the trilobites to be typical crustaceans and therefore presumed them to have two pairs of antennæ of which one pair was more or less reduced. Since only one pair of antennæ has been found, it seems appropriate to use the term antennal, segment which refers to the actual condition in trilobites.

The four post-antennal segments of the cephalon might be called the first to fourth leg-segment. Of these the last one is known as the occipital segment, and the third leg-segment as the preoccipital segment.

The preantennal, antennal and preoccipital segments seem, at least in the pleural area, to be best developed, and the first and last of these may have their distal points prolonged into spines, the former being the genal spine, the latter the intergenal spine. In the Meraspid stages of certain trilobites a pair of frontal marginal spines is found which Raw (1925) describes as procranidial spines. Raw claims three pairs of cephalic spines to be essential to the trilobite larva, and has in accordance with this little accepted view changed the name of the genal and intergenal spine into parial and metacranidial spines. Richter introduces the terms: Librigenalstachel and Fixigenalstachel, which might be convenient terms with regard to the development of the postlateral spine in the Opisthoparia and Proparia, but it indicates also that the genal spine of the Olenellidae primarily belonged to a free cheek. In accordance with the views set forth in the present paper, I prefer to maintain the common terms genal and intergenal spine.

The glabella is generally well marked in the protaspis. In the present paper the term glabella is used in the sense applied by Salter and Stubblefield (1926) i. e. including the occipital segment. This is done not only in order to avoid confusion in forms lacking a well-marked occipital segment, but primarily because the ontogeny has indicated that a five-segmented axis is a characteristic primary feature in the early trilobite larva. The five limb-bearing segments evidently form a primary unit, the occipital segments not being added at a later stage.

The postcephalic portion of the metaprotaspis forms the protopygidium. In the Meraspid Period the pygidium, through which the thoracic segments pass forward, is called the transitory pygidium.

PRESENT KNOWLEDGE OF TRILOBITE ONTOGENY

In the following the more important investigations and the major results are recorded. A more complete account of the earlier studies on trilobite ontogeny is given by Raw (1925) in his extensive paper on the larval development of Leptoplastus. Pl. 1 demonstrates the more well-known representatives of the larvæ of different trilobite groups. It appears that Cambrian forms are far better known than species from later formations. In the sequel the different trilobite families and genera are dealt with in succession.

Order *Protoparia* Swinnerton (emend.).

Family *Olenellidae* Moberg.

As pointed out by Raw (1937) and by Resser and Howell (1938) the generic name *Mesonacis* Walcott can hardly be maintained, and I have therefore followed these authors in adopting the family name of Moberg.

Our knowledge of the ontogeny of the Lower Cambrian Olenellidae is chiefly due to American workers. Already in 1877 Ford (1877, 1878, 1881) was able to describe and figure early larval stages. One of his figures which demonstrates an interesting specimen with the postcephalic segments preserved is refigured in text-fig. 3.

In his well-known paper on "Olenellus and other genera of the Mesonacidae" Walcott (1910) presented a new and far more complete material. The early larval development is known to a considerable extent in the genera *Elliptocephala*, *Olenellus*, and *Paedeumias* (most of Walcott's *Paedeumias* are identical with *Olenellus*), but many details are also known in other genera. Larval stages of Olenellidae were a few years later described by Kiær (1916) from Norway, and more recently from East Greenland by Poulsen (1932). An important discussion on the Olenellid ontogeny was given by Raymond (1917).

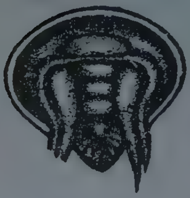


Fig. 3. Late protaspis (metaprotaspis) of *Elliptocephala asaphoides* (Emmons) from the Lower Cambrian of Troy, N. Y. S, U. S. A. 7×. After Ford 1877 pl. fig. 2.

I have made a new study of the interesting protaspis described by Kiær. By means of more modern technical equipment it has been possible to reveal more details and to arrive at a more complete conception of the structures of this important specimen which is described below.

Holmia kjerulfi Linnarsson. (?) The specimen figured in text-fig. 4, 5 e and pl. 2 fig. 6, 7 was collected by J. Schetelig in the Lower Cambrian Holmia shale of Tømten in Norway. It was described and figured by Kiær (1916, p. 66, text-fig. 11 and pl. 6, fig. 1). The preservation is good and the original relief largely maintained. The median length of the shield is 1.52 mm and the width 2.0 mm. With this size one might also consider the possibility of the specimen belonging to the larger species *Kjerulfia lata* Kiær occurring less commonly in the same beds. The size of American and Greenlandian larva of related genera, however, does not exclude the possibility of the more common species.

The outline of the shield is formed by a combined semi-elliptic anterior portion and a subtrapezoid posterior portion with the corners protruding into short spines. A slightly concave, broad rim borders the central portion in front. The postlateral corners of the rim project into short spines directed backwards. These genal spines had escaped notice in the previous description, but Raw (1925, p. 295) remarks that the sharp curvature of the sides may indicate the loci of the genal spines. The spine is preserved on the left side. Medially in the frontal portion of the rim two faint lines are indicated, which converge backwards towards a point or faint crest at the transverse glabellar furrow behind the antennal segment. It is not possible to decide, however, whether these details are accidental or belong to special structures.

The median more elevated portion of the cephalon is distinctly divided by four transverse furrows into five transverse or concentrically arranged segments. The frontal swollen ridge forming the antennal segment is curved parallel to the rim in front. The antennal segment is broadest in front where it forms the frontal lobe of the glabella. In this segment the axial furrows are very faint and become obliterated

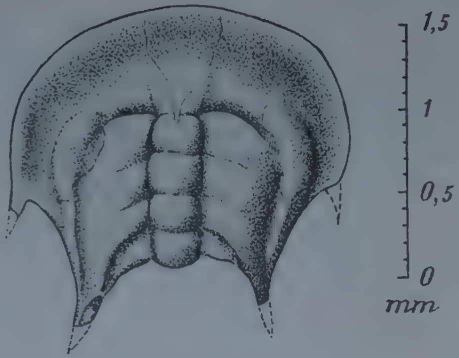


Fig. 4 Early larva (metaprotaspis or early Meraspid stage) of *Holmia kjerulfi* Linnarsson (?) from the Lower Cambrian of Tømten, Ringsaker, Norway. 22×. (Comp. pl. 2 fig. 6, 7). No. 22935 Pal. Mus. Oslo Coll.

in front. In the pleural area the antennal segment increases somewhat in width towards the middle of the eye lobes, and from here on the width diminishes towards the distal point at the lateral border of the intergenal spine. The shell is broken off at the palpebral lobes, but no traces of rudimentary eyes are indicated.

The four leg-segments behind the antennal segment are mutually much alike. The narrow glabella is well-marked by distinct, parallel axial furrows. The four transverse glabellar furrows border four distinct glabellar lobes of a subrectangular outline, the width exceeding the length. The third leg-segment, the preoccipital segment, differs from the two in front of it in having the lateral portions projected into distinct intergenal spinas. The pleural furrows bordering the segments extend only half way across the pleural area, and it is therefore difficult to decide whether some parts of the two frontal leg-segments take part in the formation of the intergenal spine. There remains no doubt, however, that the main portion of the intergenal spine belongs to the preoccipital segment. The distal portion of the intergenal spine is broken off, but the shape indicates a moderate length as shown in the text-fig. 4. The occipital segment is laterally bordered by the intergenal spines and has posteriorly a more transverse border. The transverse border might suggest that more segments were present behind the occipital one. Since the postcephalic segments are not preserved, it seems probable that the specimen described represents the earliest Meraspid stages rather than a protaspis, but it cannot be decided with certainty.

Olenellus, *Paedeumias*, and *Elliptocephala* with remarks on other genere of Olenellidae. There has been some confusion in the descriptions of species belonging to the two first genera. Since post-“telsonic” segments evidently were present in

Olenellus as shown by Resser (1928); Raw (1937) and Resser Howell (1938) point out that a number of specimens referred to *Paedeumias* by Walcott might belong to species of *Olenellus*.

The youngest Olenellid larva known is evidently an early protaspis of *Paedeumias hanseni* described by Poulsen from the Lower Cambrian of Greenland (text-fig. 5 a). The anaprotaspis, which measures about 1 mm in length, is strongly arched. The rim forming the preantennal segment is well-defined, but comparatively more narrow than in the later stages. No genal spines, only two posterior points indicate the presence of the intergenal spines, possibly including the rudiments of the genal spine. Of importance is the lack of an external segmentation of the glabella such as in later stages. The glabella is broad, vaulted and well-bordered by distinct axial furrows extending forwards to the antennal segment.

Later stages correspond to early stages of other species. Pleural furrows mark the segmentation, and the intergenal spines are seen to originate from the preoccipital segment. In an early stage (Poulsen l. c. pl. 11 fig. 6) the genal and intergenal spines seem to be united such as was assumed by Ford and Walcott. In later stages (text-fig. 5 f) the genal spine probably migrated outwards and partly forward.

Young larvæ described by Walcott as *Paedeumias transitans* show a strong development of the intergenal spines. They appear as long spines already in the Protaspis Period, and remain powerful up to late Meraspid stages (Walcott 1910, pl. 25, fig. 22; pl. 32 fig. 1—8).

Elliptocephala asaphoides Emmons is known in greater detail. Walcott (1910) describes and figures a number of small stages of which some are reproduced in text-fig. 5 b, c, d and pl. 1, fig. 1, 2, 3. The length of the smallest specimen (b) is 0.8 mm and the next one (c), which is not much different, has a median length of not less than 1.4 mm. Since a further advanced stage (d) measures only 1.0 mm, it is possible that the second stage belongs to another species. The two earliest stages belong to the Anaprotaspid Period and the third one to the Metaprotaspid Period Degree 1, on account of the addition of one postcephalic segment. In the smallest specimen the preantennal segment has a broad marginal rim, and the segment cannot, according to Walcott's figure from 1910, be separated from the antennal segment. In the original illustrations of Walcott from 1886 and 1890, however, the anterior border of the antennal segment is suggested by a lack of shading such as shown in the present text-fig. (b).

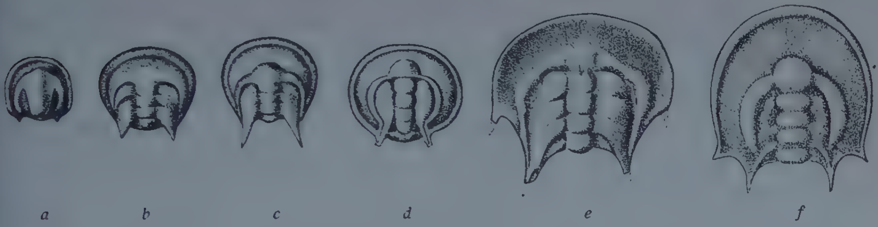


Fig. 5. Early larval stages of different species of Olenellidae from the Lower Cambrian. *a*=anaprotaspis of *Paedeumias hanseni* Poulsen from Ella Island, Greenland. 9.9×, (after Poulsen 1932 pl. 11 fig. 4). *b*—*d*=anaprotaspides (b, c) and metaprotaspis (d) of *Elliptocephala asaphoides* (Emmons) from Troy, N. Y. S., U. S. A. *b*=13.8×, *c*=8.5×, *d*=8.8×. (after Walcott 1889 pl. 88 fig. 1, 1 a, 1916 pl. 25 fig. 1, 9, 10). *e*=early larva of *Holmia kjerulfi* (Linnarsson) (?) 12.7× (comp. text-fig. 4). *f*=cephalon of Merspid Period of *Paedeumias hanseni* Poulsen from Ella Island, Greenland. 9.9× (after Poulsen 1932 pl. 11 fig. 7).

The anaprotaspis demonstrates in an interesting way the primitive concentric arrangement of the cephalic segments. The intergenal spine belongs to the preoccipital segment, but the pleura of the second leg-segment seems to take part in the formation of the spine. In the larger protaspides the antennal segment is well bordered. It is possible that the smallest specimen might represent the last but one of the Anaprotaspid stages, and this possibility is indicated in the plate by an arrow suggesting a possible different position of fig. 2.

In the first Metaprotaspid stage the axis is not indicated in the protopygidium (d), but this might be due to preservation. The glabella and antennal segment are very distinct, but the pleural furrows have become obsolete. The postlateral portions of the preantennal segment have increased in size, but the genal spines are not yet separated from the intergenal spines, such as in somewhat larger specimens (pl. 1, fig. 3).

The beginning of the Meraspid Period is difficult to determine with certainty. The presence of separate cephala at a median length of 1.3 mm and with the genal and intergenal spines just separated, suggests that only one, two, or at least a few Metaprotaspid stages occurred. Postcephalic segments are preserved in a small specimen figured by Ford (1877) and depicted in text-fig. 3, but it is not possible to decide whether it represents a late Metaprotaspid or an early Meraspid stage. In the plate two Metaprotaspid stages are suggested. Future research and a more accurate determination of the size of each stage might determine the number.

The larval development of other Olenellidæ described by Walcott corresponds in general characters to those described above. (Only one drawing of *Wanneria* (l. c. pl. 31, fig. 8) suggests an extra glabellar segment, but this drawing is hardly correct). The early Meraspid stages are demonstrated in *Holmia rowei* Walcott (1910, pl. 29, fig. 9), *Wanneria halli* Walcott (l. c. pl. 31, fig. 5—8) and *Olenellus lapworthi* (Peach) (l. c. pl. 39, fig. 6).

The development of cephalic spines. During the Meraspid Period the development and reduction of cephalic spines might be studied. The origin and homology of the cephalic spines have recently been subject to considerable discussion. In several recent papers Raw (1925, 1927, 1937) has presented a new interpretation of she cephalic spines, an interpretation which also involves new conceptions of the cephalic sutures. In the following the marginal spines are dealt with in connection with the views set forth by Raw.

As mentioned above the intergenal spine of the metaprotaspis of *Elliptocephala* (pl. 1, fig. 3, 4, text-fig. 5 d) appears to include also the genal spine. A line indicates the border between the two portions. In a next stage the two spines are just separated. Although the accurate division is not demonstrated in the material described, it seems highly probable that Ford and Walcott were right in assuming that the primary spine became divided and the lateral spine migrated outwards and remains as the genal spine.

In *Paedeumias* (or *Olenellus*) (text-fig. 5a, f, and Walcott 1910, pl. 25, fig. 22; pl. 32, fig. 1—8; pl. 34, fig. 1—4) the intergenal spines are strongly developed in the earliest stages, and the genal spines appear already in the protaspis as sharp points and remain as such through the Meraspid Period or perhaps early Holaspid Period. There seems to be hardly any reason to doubt that the reduced intergenal spines are represented by the small points just inside the genal spines.

In *Wanneria* (l. c. pl. 31, fig. 1—8) the intergenal spines are well-developed in early stages and become reduced in later stages. The genal spine lies near the intergenal spine in a small cephalon measuring about 1.1 mm in length, and in later stages the genal spine seems to migrate forward.

Olenellus gilberti Meek (l. c. pl. 36, fig. 13, 14) has in the early Meraspid stage both spines situated near each other at the genal angle, but in addition to these a pair of small antelateral marginal points occur. The points, which are called procranidial spines by Raw, are much reduced already at a cephalic length of 3.5 mm. There is no evidence of a posterior migration of the procranidial spines.

In *Olenellus fremonti* Walcott (l. c. pl. 37, fig. 1—20) the earliest stages are not known, but in a cephalon measuring 2.0 mm (?) in length the genal spines are already well-developed and have a lateral position with the spines directed outwards and backwards. In further stages the genal spines migrate forward to the anterior border where they remain in certain species *O. bristolensis* Resser (1928, pl. 2, fig. 5—8) while in others, *O. fremonti*, they migrate slightly backwards again in the latest stages. A considerable individual variation seems to occur.

As pointed out by Beecher, Raymond, and others, the small *Olenelloides*, with only seven thoracic segments, probably represents a larva of an Olenellid. In this form the procranidial, genal and intergenal spines are equally well-developed, the cephalon measuring 2—2.5 mm in length (pl. 40, fig. 2—3).

It was the structures in *Olenelloides* and particularly an early Meraspid stage of the Olenid *Leptoplastus* (see below) which led Raw to a new conception of the nature of the spines and sutures in the Olenellidæ. Raw presented his views in his important paper on the larval development of *Leptoplastus salteri* (Callaway). The work gives a detailed description of the post-protaspid development of this species, and at the same time presents a detailed account of the ontogeny of other genera and species which he has personally examined. In the early Meraspid Period, Degree I (pl. 1, fig. 31), three pairs of spines as well as a nuchal spine are present. Raw postulates that this "Heptacicephalic Stage" demonstrates a primary plan of construction of the trilobite head and therefore is of great phylogenetic importance.

In *Olenelloides* Raw sees a representative of this arcaic structure. He regards the small form to be essentially adult on the somewhat vague grounds that *Olenellus gilberti* has attained more adult characteristics at the corresponding size. Since certain Olenellids have three pairs of spines, Raw raises the question which of these three remain in forms with only one or two pairs of spines.

The intergenal spine (metacranidial) Raw finds to belong to the occipital — not preoccipital — segment. He bases his opinion on what then was known of the larva of *Paradoxides* (see below) and at the same time on the general resemblance of the occipital segment and the first segment of thorax. Recent studies of the mentioned genus have strongly indicated that the spine belongs to the preoccipital segment, but on the other hand I agree with Raw that the intergenal ridge of Kiær is similar to the anterior border of the pleural furrow in the thoracic segment. This difficulty is, however, eliminated by assuming a secordary division of the segments such as presented below (p. 124).

The procranidial spine occurs on the median side of the facial suture in *Leptoplastus*, and this would correspond to a position just above the connective sutures in forms where such sutures were present. Raw deduces logically that in Olenellida, with its very broad rostrum, the procranidials would be expected to be located near or at the place of the genal spines. He finds a support for this assumption in the faint line running from the front of the eye backwards towards the genal spine (comp. p. 137). A backwards migration of the procranidial spine is, however, not demonstrated in the ontogeny. The opposite case, the forward migration of the genal spine in *Olenellus fremonti*, is explained away by Raw by doubting that the smaller larva belongs to this species. The similar conditions in *Wanneria halli* are not commented upon. As regards the larva of *Elliptocephala* he indicates that instead of a separation of primarily fused spines, as presumed by Ford and Walcott, a secondary fusion of the procranidial and genal (parial) spine took place so that the genal spine of the adult actually was composed of both the procranidial and genal spines (text-fig. 5). In *Olenellus thomsoni*, described by Walcott as *Paedeumias transitans*, Raw claims that the genal spine is formed by the procranidial only and that both the other spines are reduced.

The conclusions drawn by Raw met criticism by Swinnerton (in Raw 1925) who points out that too much importance was attached to the particular cephalic spines which are common among planktonic larval forms of crustaceans and which are so rare among the trilobite larvæ that their occurrence rather is an exception than a rule. The conditions in the Olenellidæ (Mesonacidæ) indicate that the spines actually migrate forward and thus contradict Raw's hypothesis. Raymond (1928) expresses similar views.

Stubblefield (in Raw 1936), in commenting upon a later paper by Raw, points out that the intergenal spine in the Olenellidæ was connected with the preoccipital segment and not with the occipital segment as claimed by Raw. Stubblefield (1936) discusses in a separate paper the theory set forth by Raw and finds little support to his interpretation of the cephalic spines.

In reply to Stubblefield's criticism concerning the interpretation of the intergenal spine, Raw (1937, p. 580) points out the resemblance between the transverse furrows in the cheeks of the larvæ, and the pleural furrow both in thoracic segments and in the pygidium. Since they must be regarded as homologous formations, he consequently arrives at the conclusion that the transverse or oblique furrows in the cheeks of the larva do not represent segmentary division lines, but are intersegmental. For this reason he finds it natural to regard the intergenal spine as belonging to the last cephalic segment.

Concerning the interpretation of the intergenal spine, I find that both views might be subject to certain criticism. It seems highly reasonable, as did Walcott, Kiær, and Stubblefield, to regard the cheek-furrows in the early larva of Olenellids as division-lines bordering the primary segments. On the other hand it is less logical, as pointed out by Raw, to interpret these furrows in another way than those of thorax and pygidium. Following Raw's interpretation, however, which is based on the structure of the thoracic pleura, we are lead to the little satisfactory conception of the larval cheek-furrows being but intersegmental furrows serving as apodemes of muscles. As shown below, the two views might be combined by regarding the pleural segmentation in the thorax as a secondary formation (p. 124).

With regard to the origin and homology of the cephalic spines, I agree with Swinnerton, Raymond, and Stubblefield in their criticism of the theory presented by Raw. It deserves to be strongly pointed out that in the trilobite larvæ the three pairs of marginal spines are hitherto only found in Meraspid stages. Pl. 1 demonstrates the lack off such spines in all known Protaspid stages. Spines of the ordinary type (intergenal or genal) are present in the Protaspid Period of many species, and are probably strongly developed in *Tretaspis*. The procranidial spines occur in a small number of species, although they may to a certain extent have been overlooked, as pointed out by Raw, on account of their different direction.

It seems natural to assume that the development of spines in the early larval stages was due to the floating habits of the small larva. Concerning the revolving backwards of the procranidials in the Olenellidæ, the development of *Wanneria* and *Olenellus fremonti* seems to contradict this assumption. The interpretation of the genal spine in *Olenellus thompsoni* (=*Paedeumias transitans* pars) as a procranidial spine is difficult to follow. It seems more probable to assume that the intergenal spine was maintained through a number of Meraspid stages before it became reduced and functionally replaced by the genal spine. The small indication of a point within the intergenal spine (Raw 1927, fig. 23) does not need to be regarded as a vestige of a reduced spine.

In interpreting the cephalic structures of the Olenellidae, Raws' major grounds for his new views are the long rostrum and the faint line which he explains as an obliterated anterior branch of the facial suture. The long rostral plate and the marginal suture might be explained as a primary structure as shown below. The faint line leading from the eye does not cross the margin and is of little importance as discussed below (p. 138).

Order *Hypoparia* Beecher.

Family *Cryptolithidae* Angelin.

Larval stages of *Cryptolithus* and *Tretaspis* have been described by Barrande (1852, pl. 30 fig. 41—50), Størmer (1930, pl. 7, pl. 8, fig. 1—4) and Whittington (1940, pl. 1 fig. 1—3, pl. 2 fig. 1—3) from Ordovician beds of Bohemia and Sweden. Unfortunately no protaspis stage is known, but the Meraspid stages are known in detail both in *Cryptolithus* (*Onnia*), *ornatus* (Sternberg) (text-fig. 11, *6*, *7*) and *Tretaspis seticornis* (Hisinger) (pl. 1 fig. 41).

In the earliest Meraspid Period the cephalon is much broader than what is characteristic of all other known trilobites (*Corydocephalus* is also broad). A special feature is also the lack of glabellar furrows. As I have pointed out in *Reedolithus* and *Tretaspis* (l. c.), the glabellar furrows do not appear until a comparatively late stage of development. The glabella of *Tretaspis* has a well-developed median tubercle which has been interpreted by Hanström (1934) as identical with special structures in recent Syncarida among the Crustacea.

Already in Degree O of the Meraspid Period the marginal rim and the long genal spines are well-developed. The cephalic suture is marginal, but runs on the dorsal side of the genal spine, not on the ventral side as in the Olenellidae. The rudimentary lateral eyes lie well within the margin.

The segmentation to the transitory pygidium is not distinct in the early Meraspid stages, but, as may be seen in text-fig. 11, 7, the pleural furrows form a distinct angle to the transverse suture separating the cephalon and transitory pygidium. Transverse lines marking borders of the in future free segments are not seen in the pleural areas.

? Family *Agnostidae* McCoy.

Barrande (1852, pl. 49) figures larval stages of several Middle Cambrian genera and species of which one is reproduced in fig. 42 on pl. 2. No protaspis is described, but the earliest stage probably represents Degree 0 of the Meraspid Period. No segmentation is expressed in the axis of cephalon or pygidium, but it is interesting to notice that the glabella is far from reaching the anterior border.

A smaller specimen described by Matthew (1896, p. 216), measures only 0.5 mm in length. Neither in this early stage the axis or glabella reach the anterior border, but has the same extension as in the adult. The axis has apparently three crossing furrows.

Future discoveries of protaspides of Agnostidae might solve the problem of the systematic position of this peculiar group. It is, however, interesting to notice that the early larvæ seem to deviate considerably from the protaspis of *Microdiscus*, a feature which might suggest that they belong to different Orders.

? Family *Shumardidae* Lake.

The genus *Shumardia*, comprising quite small forms from the basal Ordovician, has been compared partly with the Agnostidae and Trinucleidae, and partly with the Olenidae and Conocoryphidae. The larval development of the genus has become known through the detailed study by Stubblefield (1926) on *Shumardia pusilla* (Sars) from Shropshire, England. As might be seen from the figures reproduced on the plate (fig. 43—45) the larval stages are very small, the earliest one measuring only 0.24 mm in length.

The strongly arched early protaspis (text-fig. 6, *1*,and pl. 1, fig. 43) has an axis of six segments. Of these only four are referred to the cephalon because of a faint line across the cheeks behind the fourth segment and because of the apparently four-segmented glabella in

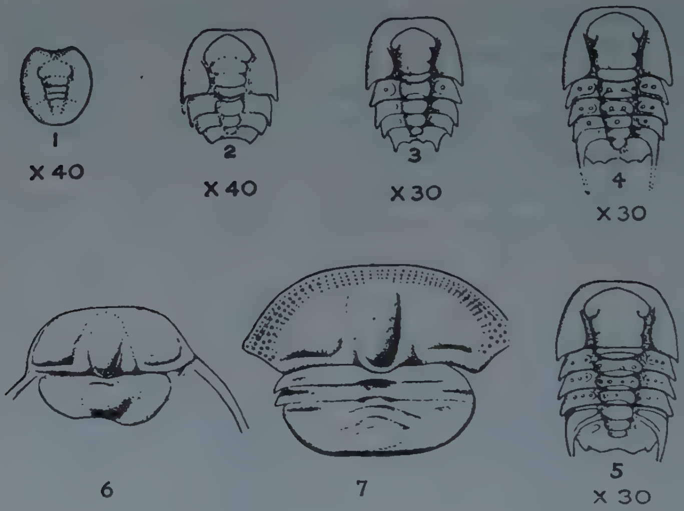


Fig. 6. 1—5 = early larvæ of *Shumardia pusilla* (Sars) from the Lower Ordovician of Shropshire, England. Magnification given in the figures. 1 = metaprotaspis, 2—5 = Meraspid stages (after Stubblefield 1926 pl. 14 fig. 1—5).
6—7 = Early larvæ of *Cryptolithus* (*Onnia*) *ornatus* Sternberg, from the Ordovician of Bohemia. 6 = Meraspid Period Degree 0, ×23; 7 = Meraspid Period Degree 2, 23×. (After Whittington 1940 pl. 1 fig. 1, 3.)

later stages. If this was the case *Shumardia* would deviate from the other known trilobites. I am more inclined to believe that the faint line across the cheek represents an oblique or pleural furrow marking the border between the pleuræ of the preoccipital and occipital segments. The line would thus indicate the posterior border of the pleura projecting into the intergenal spine. In that case the described protaspis must be interpreted as a metaprotaspis of Degree 1.

The next stage found (text-fig. 6, *2* and pl. 1, fig. 44) exceeds the former considerably in size by having an average length of 0.37 mm. Probably at least one intermediate stage occurred as suggested on the plate.

Stubblefield mentions that the cephalic portion of the protaspis has a pair of anterior projections and an antemedian depression which quickly becomes obsolete.

The specimens of Degree 0 of the Meraspid Period show a remarkable variation both in size (0.31—0.50 mm) and in the development of the segments of the transitory pygidium. The smaller specimens had three segments and the larger ones four. The same variation occurs in late Meraspid stages. This indicates that an extra moulting took place within one Degree of the Meraspid Period.

The major result obtained through Stubblefield's studies is the demonstration of the manner in which new segments are formed at the posterior border and from here on successively migrate forward during the growth and the further addition of new segments. This is shown by the gradual forward migration of the long-spined pleura belonging to the fourth thoracic segment in the adult. The spine might be followed, as shown in text-fig. 6 *3—5*, through the transitory pygidium before it becomes released as part of a free thoracic segment.

Order *Proparia* Beecher.

Family *Phacopidae* Corda.

The larval development of the Ordovician species *Dalmanitina socialis* Barrande was described by Barrande (1852, pl. 26, fig. 1—4). The length of the first three stages is stated to be: 0.75, 0.75, and 1.0 mm. In fig. 36—38 of the plate the stages are reproduced corresponding to these sizes, but the measurements probably were only approximate and the second stage therefore probably was intermediate between the first and third. Barrande's figures are depicted by Beecher (1895, pl. 9, fig. 8—10), but they are not correctly redrawn as pointed out by Warburg (1925). Thus in the earliest stage Beecher indicates three segments in the protopygidium while only two were faintly shown and two fused segments were mentioned in the text. Beecher describes the three earliest stages (fig. 36—38 on the plate) as belonging to an anaprotaspis, metaprotaspis, and paraprotaspis stage. Since already the youngest stage has postcephalic segments developed, it is obvious that these stages belong to the Metaprotaspid Period. A fourth stage figured by Barrande (l. c. pl. 26, fig. 4) is said to have one free thoracic segment, and the preceding stage, which apparently had the same number of segments, must therefore be regarded as Degree 0 of the Meraspid Period, such as is indicated in the plate. The transverse suture is difficult to distinguish, but for the reasons mentioned it is natural to regard the two first stages as belonging to the Metaprotaspid Period and the third to the Meraspid Period. The metaprotaspid stages seem to belong to Degree 2 and 3, or 3 and 4, on account of the development of the axis of the protopygidium.

The protaspis of *Dalmanitina* exhibits several characteristic features indicating an advanced stage of development. The intergenal spines which remain as "genal" spines in the adult are well-developed in the early metaprotaspis. As in *Calymene* no trace of the preantennal segment is visible. The lateral eyes are situated at the frontal margin where they remain for a considerable part of the Meraspid Period. In the adult the facial suture has a typical proparian course. Following the course of the suture backwards through the Meraspid stages, Barrande's drawings indicate that the facial suture in the earliest stages was more or less marginal, and then migrated inwards across the antelateral corners.

The protopygidium is well-developed in the early stages. In the last metaprotaspis both pleural furrows and division-lines marking future thoracic segments are indicated.

? Family *Eodiscidae* Raymond.

Matthew (1896) describes a protaspis which he refers to the species *Microdiscus pulchellus* Hartt. The protaspis measures slightly over 0.5 mm in length. The outline is almost circular, the distinct axis reaching the anterior border and divided into a number of annulations, the five anterior ones belonging to the cephalon which is separated from the protopygidium by a faint transverse furrow. The protaspis probably belongs to Degree 2 of the Metaprotaspid Period.

In general characters the protaspis of *Microdiscus* corresponds closely with the protaspis of the typical Proparia and Opisthoparia. This is of interest in suggesting that the Eodiscidae belong to the Proparia as indicated in the facial sutures of *Pagetia*.

Order *Opisthoparia* Beecher.

Family *Paradoxididae* Emmrich.

Series of larval stages of *Paradoxides* were described by Barrande in his classical memoir on Bohemian trilobites (1852), but on account of the very particular development of the glabella in the early stages, Barrande described them as belonging to a special genus which was called *Hydrocephalus*. Later authors, Raymond (1914 a), Raw (1925), Šuf (1926), and Westergård (1936), have succeeded in identifying the different "species" of *Hydrocephalus* and refferred them to respective species of *Paradoxides*. An abnormal spheric development of the glabella is characteristic of *P. spinosus* (Boeck) in particular, but also *P. rugulosus* Corda shown in text-fig. 7, g, h, differs considerably from other tribolite larva.

Till recent years little was known of the earliest larval stages of *Paradoxides*. Raymond (1914 a) described an interesting protaspis specimen from Bohemia (text-fig. 7, f, and pl. 1, fig. 6) which is not unlike the protaspides of the Olenellidae. The protaspis has an ovate outline with the intergenal spines partly broken off. The glabella is divided into distinct segments of which the frontal lobe and the next segments are divided by a median furrow characteristic of all *Paradoxides* larvæ. The frontal lobe is stronger developed than the three following which are mutually alike. According to Raymond (l. c. p 232) a small posterior projection behind the occipital segment seems to represent the protopygidium. This would indicate that the specimen represents a first metaprotaspis as suggested in the pl. 1 fig. 6. The palpebral lobes are strongly developed and reach as far as to the occipital segment. Of particular interest is the development of the preantennal segment. It is exposed in front of the glabella and the palpebral lobes, but is not visible laterally in the posterior half of the cephalon. The broad rim characteristic of the Olenellidae does not occur, only a part of it is maintained in front.

More complete knowledge of the ontogeny of the Paradoxididæ has been obtained recently through the detailed and interesting descriptions of Westergård (1936) of *Paradoxides* larvæ from Öland in Sweden. Text-fig. 7 a—e illustrates some of his more important youngest stages which probably belong to the species *P. pinus* Holm MS.

The smallest protaspis (a) measures 0.60 mm in length. The circular shield is strongly vaulted especially in transverse direction. The glabella is distinct with the axial furrows diverging in front so that the frontal lobe of the glabella is broader than the four succeeding segments which are mutually alike. From the frontal lobe, which is divided by a median furrow into two hemispheres, the palpebral lobes extend outwards and backwards as two arcs following the lateral margin and reaching to the posterior margin not far from the axial furrows. The preantennal segment is only exposed in front of the glabella and the palpebral lobes.

Since the described protaspis has five distinct segments in the axis, it must be regarded as a late anaprotaspis.

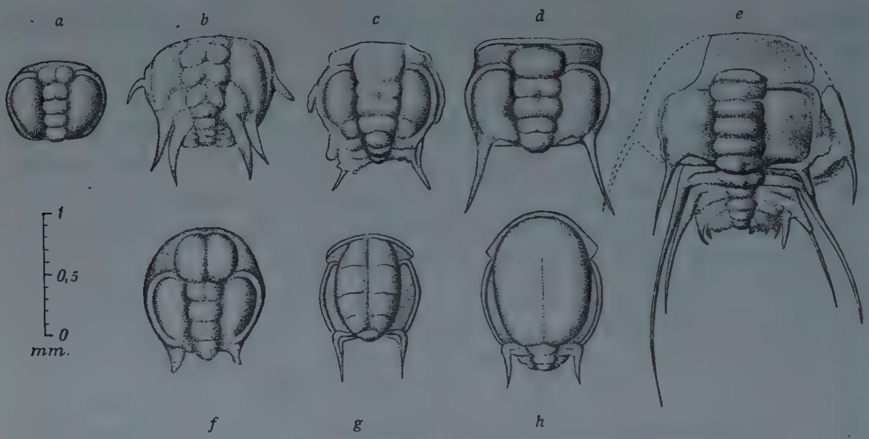


Fig. 7. Early larvæ of *Paradoxides* from the Middle Cambrian. 16×. *a*–*e*=*Paradoxides pinus* Holm MS (?) from Öland, Sweden. *a*=anaprotaspis, *b*—*c*=metaprotaspides, *d*—*e*=Meraspid stages. (After Westergård 1936 pl. 4 fig. 1 b, 4 b, 8, 13 a, b. *f*=*Paradoxides* sp. from Teirovic, Bohemia. Metaprotaspis. (after Raymond 1914a pl. fig. 8, median furrow somewhat shortened according to description). *g*, *h*=*Paradoxides rugulosus* (Barrande) from Skreje, Bohemia. Meraspid stages. (*g* after Šuf 1926 pl. 1 fig. 1; *h* after Barrande pl. 49 fig. 1 b.)

A later protaspis stage demonstrated in two specimens figured in text-fig. 7, b, c, (Westergård 1936, pl. 4, fig. 3, 4 a, b) is of particular interest because of the presence of three pairs of spines. The stage apparently represents Degree 3 of the Metaprotaspid Period. In the first specimen (b) the preservation of the anterior portion is not satisfactory. In order to obtain further details on the structures of the specimen, I wrote to Dr. Westergård who kindly informed me that he and Dr. P. Thorslund on my request had submitted a new investigation of the specimen. I am very thankful to Dr. Westergård and Dr. Thorslund for the new information which I have used in the following description.

In the two mentioned specimens the glabella, especially the frontal lobe, is not well preserved. The drawing of the first specimens by Westergård (l. c. pl. 4, fig. 4 b) might indicate a rim in front of an only four-segmented glabella. Westergård has informed me that the traces of a lobe might be seen on the right side in front. This indicates, what would be expected, that the frontal lobe is lost or buried in the matrix. Traces of it is therefore indicated in text-fig. 7 b. The glabella is, however, demonstrated in so many specimens (e. g.

text-fig. 7 c) that there remains no doubt as to the shape and segmentation of the glabella. Text-fig. 17 c and fig. 7 on the plate show a reconstruction of the glabella in the metaprotaspis. The frontal lobe is broader than the succeeding three segments which again are slightly broader than the occipital ring. A median furrow divides the glabellar lobes into two halves. The palpebral lobes follow the lateral margin, cross the basis of the genal spines and are traced as far as to the intergenal spines.

The three pairs of spines are easily identified as the genal spines (in front), the intergenal spines and the pleural spines of what later becomes the first free thoracic segment. The short genal spine is directed outwards and backwards from its base lateral to the third glabellar lobe. The drawing (text-fig. 7 b) indicates a line across the base of the genal spine. Westergård finds that the preservation does not permit an identification of the structure as a marginal suture.

The intergenal spine is very distinct and situated at the postlateral angle of the cephalon. In contrast to what previously was assumed to be the case in the Paradoxididae, the intergenal spine apparently is connected with the preoccipital, not the occipital segment of the glabella. In his description Westergård states that the spines: "seems to form the pleural terminations of the penultimate (?) cephalic segment." After the new study of the specimen, Westergård informed me that it might be said with fairly great probability that the spines belong to the preoccipital segment. In that case the structures correspond very well with those in the Olenellidae. In the Bohemian specimens of Paradoxididae (Šuf 1926) the abnormal development of the glabella has confused the structures (text-fig. 7, g, h), but even in young stages of *P. Spinosus* (Šuf l. c. pl. 3, fig. 2) a preoccipital origin of the spines is suggested.

The pleural spine, following immediately behind the intergenal spine, is very similar to it. The occipital ring, with its small median tubercle, has on either side a pleural lobe corresponding to that of the preoccipital segment. These lobes are separated from the pleural spines by a faint transverse furrow. The transverse furrow or line evidently corresponds to the course of the transverse suture dividing the transitory pygidium from the cephalon in the first Meraspid stage.

Since both spines appear to be homologous structures and to belong to succeeding segments, we must regard the first one, the intergenal spine, as belonging to the preoccipital segment, and the second one as belonging to the occipital segment. But then we are forced to assume that the transverse line, later becoming a suture, is a secondary formation, a secondary suture crossing the primary segment with its pleural portion directed backwards. A pointed out in a later chapter, the pleura of the so-called occipital segment would thus be composed of parts of two segments: an antelateral portion belonging to the preoccipital segment and a postmedian portion formed by parts of the occipital segment.

In the early Meraspid Period the Swedish Paradoxides (text-fig. 7, d, e) have well-developed intergenal spines, but already in Degree 4 the spines are reduced into a pair of blunt points. In the transitory pygidium the lay-out of a transverse suture might be observed in the segments of the transitory segments before they arrive at the anterior border. This is seen in Degree 4 (l. c. pl. 4, fig. 22), but it is not significant in Degree 1 (text-fig. 7 e).

During the Meraspid development the median furrow of the glabella becomes reduced. In the Protaspid Period the glabella is divided into five distinct segments such us in other trilobites. In the earliest Meraspid stages a new pair of glabellar furrows, the antennuary pits, appear on the frontal lobe of the glabella. The furrows might unite medially as in the specimen shown in text-fig. 7 e, and this gives the impression that the glabella includes six segments instead of five as demonstrated in the earliest larval stages. A similar condition is found in adult specimens of the Lower Cambrian *Callavia* belonging to the Olenellidae. The larval development of *Paradoxides* and *Olenus* shows, however, that the anterior furrows come into being at a certain later larval stage and therefore hardly can be said to belong to the primary segmentation of the glabella. As discussed below, it is probable that the frontal impressions are apodemes belonging to the muscles of the antennæ which represent the appendages of the first glabellar segment.

The prostaspis of *Paradoxides* differs considerably from the same larval stage in the Olenellidae. This is especially the case with the Swedish protaspis (text-fig. 7 a). Raymond (1914) and others, on the other hand, have pointed out that the protaspis described by him (text-fig. 7 f) exhibits unmistakable Olenellid resemblance. The main difference is found in the presence of a well-developed preantennal segment in the Olenellidae. In Paradoxididae this segment is little developed in the dorsal shell. Only in front a portion of the segment is exposed. The palpebral lobes, which in the Olenellidae lie well within the marginal rim or preantennal segment, form the lateral borders in the Paradoxididae.

The course of the facial suture is well demonstrated already in the earliest Meraspid stages, occurring as cranidiæ (text-fig. 7 d). In the metaprotaspis (7 c) the suture cannot be distinguished with certainty, but the presence of the genal spine close to the palpebral lobe leaves no doubt that the facial suture at this stage was practically marginal, thus forming a marginal suture crossing the base of the genal spine. In the anaprotaspis the suture was evidently marginal, and no genal spine was apparently developed. It seems probable that this larval marginal suture was confined to the anterior half of the protaspis shield. This is supported by the conditions in the Olenidae where the suture of the early Meraspid larva crosses the antelateral corners of the cheeks and thus is of the proparian type (Poulsen, 1923). Also in *Limulus* the marginal suture serving the ecdysis is confined to the frontal half of the shield.

During the Meraspid Period the preglabellar field develops rapidly. Especially the antelateral corners of the cephalon grow faster than the rest of the cephalon. This results in a new course of the preocular branch of the suture. From having an antemedian direction in the protaspis, it runs straight forward in the early Meraspid Period and is directed forward and outwards in later stages. During the Meraspid Period the area outside the palpebral lobes, the free cheeks, increases in width. The suture keeps its connection with the palpebral lobe, or more correctly, the eye, and therefore crosses the cephalon as a typical cephalic suture instead of being marginal as in the earliest larvæ.

It appears from what is set forth above, that the larval development of the Paradoxididae is pretty well known. The early larvæ differ in certain respects decisively from those of the Olenellidae.

Family *Olenopsidae* Kobayashi.

The genus *Olenopsis* was established by Bornemann (1891) to include species which in several features show both Paradoxidid and Olenid characteristics. According to Cobbold (1931) the genus seems to occur in late Lower Cambrian or possibly slightly younger beds. In his monograph on Cambrian fossils from Sardinia, Bornemann also describes a number of young stages of *Olenopsis*. The published drawings appear to be somewhat schematic as might be judged from those redrawn in fig. 25 and 26 of pl. 1, but there are certain distinct features which are present in many specimens and are evidently characteristic of the species.

The small protaspis shows the characteristic five-segmented axis just as in the anaprotaspis of other trilobites. The exact nature of the long palpebral lobes is not clear. Of special interest is the presence of four pairs of oblique furrows crossing the cheeks. Each furrow runs from the corresponding glabellar furrow in an arc outwards and backwards forming a distinct angle to the hind border. The described furrows are evidently homologous with the furrows across the cheek of the protaspis in Olenellidae and Olenidae and apparently represent primary segmentary division lines.

Family *Damesellidae* Kobayashi.

Endo (1935 a, 1935 b) has described the larval development of *Blackwelderia quadrata* Endo from the Middle Cambrian of the Fengtian Province in Manchukuo. A number of protaspis specimens are figured and referred to different stages in the larval development, but the variation in size is so considerable that all specimens can hardly be referred to the same species.

Of special interest is a very early protaspis refigured in pl. 1, fig. 10. The early anaprotaspis appears as a circular vaulted disc with only indications of a short unsegmented axis or glabella. A somewhat later stage (fig. 11) has, according to the drawing presented by Endo, a broad glabella reaching from the anterior to the posterior border and provided with faint transverse furrows. A late anaprotaspis (fig. 12) shows considerable resemblance to the same stage in *Paradoxides*. The circular shield has the same long marginal palpebral lobes and the frontal lobe of the glabella is expanded. Already in this early stage a pair of small pits on the frontal lobe is indicated which might represent the antennuary pits appearing in later stages in other genera. The drawing is, however, rather schematic.

Family *Liostracidae* Angelin.

Already in an early paper from 1875 Brøgger figures a fairly complete series of early larval stages of *Liostracus linnarssoni* Brøgger from Middle Cambrian beds of Øksna in Norway. His illustrations, which are shown in text-fig. 1 of the present paper, were reproduced by Lindström (1901) who added a theoretical earlier stage.

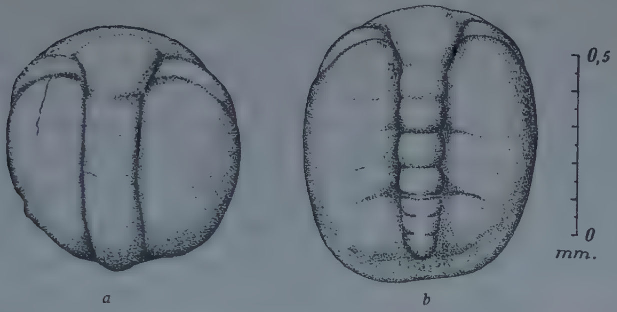


Fig. 8. Protaspides of *Liostracus* (?) from the Middle Cambrian of Øksna, Norway. 47×. (comp. pl. 2 fig. 2). *a* = anaprotaspis, *b* = metaprotaspis. Nos. 27162 a, b Pal. Mus. Oslo Coll.

Matthew (1888) has described an ontogenetic series of an American form, but the youngest stages were not present. More recently Warburg (1925) figures Swedish specimens, and arrives at the conclusion that the protaspis has distinct swollen eye-ridges which the author calls the "larval ridge" and compares with the antennal segment in the protaspis of Olenellidae. It has become evident from later studies, however, that the larval ridge does not form the anterior margin of the shield (Strand 1927) and that it neither represents the entire width of the antennal segment or "larval ridge" such as in the Olenellidae.

Warburg describes the traces of a segmentation of the cheeks, but the author points out that some of the lines might be pleural furrows and some segmentary division lines. The furrows of the protopygidium are not distinct (l. c. text-fig. 6).

In order to obtain further information on the larval structures in *Liostracus*, I have tried to locate some of Brøgger's type material. Among the collections of the Paleontological Museum in Oslo I have succeeded in finding a few specimens from Øxna which are apparently not the types, but are similar specimens. Text-figs. 8 a, b and pl. 2, fig. 3 illustrate two specimens of which the one (8 b) at least with great probability belongs to *L. linnarssoni*. The younger stage (8 a), representing an anaprotaspis, is comparatively larger than the other being a metaprotaspis, and it is therefore possible that the form might belong to another species.

The anaprotaspis (text-fig. 8 a) is moderately vaulted with a circular outline and a glabella bordered by distinct axial furrows. The glabellar furrows are very faint except those behind the frontal lobe. It is of particular interest to notice that the frontal lobe also is bordered in front, distinguishing a preantennal segment in front of the glabella and the well developed eye-ridges.

The metaprotaspis (text-fig. 8 b) appears to have a three-segmented axis of the protopygidium, and therefore probably belongs to Degree 3 of the Metaprotaspid Period. The shield has an elliptical outline and the surface of the cheeks is strongly vaulted. The glabella is divided into five distinct segments of which the frontal lobe is expanded in front. The frontal lobe is but slightly marked off from the preantennal segment, only exposed as "tapering ridges" in the median portion in front of the axial furrows. The cheeks have traces of furrows near the glabella. The direction of the furrows is apparently more transverse than in *Olenus* and *Olenopsis*. The protopygidium has an indication of a posterior rim as shown in the drawing.

Family *Solenopleuridae* Angelin.

The ontogeny of the Middle Cambrian *Sao hirsuta* Barrande from Bohemia has become famous through the detailed and excellent description by Barrande already in 1852. He was able to distinguish a large number of evolutionary stages from the protaspis up to the adult.

The earliest stage described (Barrande 1852, pl. 7, fig. 1) (fig. 27 on the plate), consists of a circular shield. The surface is arched, but not necessarily very strongly arched as stated by Warburg on account of the absence of the larval ridge. The profile of the following stage (l. c. pl. 7, fig. 1 c) indicates that this stage at least was moderately convex along the median line.

The glabella is well marked already in the earliest stage, but distinct glabellar furrows do not appear until later stages (pl. 1, fig. 29, 30). As stated by Barrande, the occipital ring is separated from the rest of the glabella and, by comparing the earliest with the somewhat later stages, it seems possible to distinguish the occipital segment also in the first stages. It then appears that the smallest specimen (pl. 1, fig. 27) is no anaprotaspis as assumed by previous authors, but represents an early metaprotaspis probably of Degree 1, since one segment is suggested beyond the occipital ring. As indicated in the position of the stages on the plate (fig. 27—30), the Anaprotaspid Period is not known in this species. The slight differentiation of the dorsal structures in the earliest metaprotaspis might suggest that the larva was hatched at a comparatively late evolutionary stage.

Most of the Anaprotaspid stages might have been passed through with in the egg.

In the next stage (pl. 1, fig. 28) two axial rings are present beyond the segment interpreted as the occipital segment. The posterior margin of the circular protaspis has three pairs of points or spines of which the two posterior pairs belong to the protopygidium. Concerning the first pair of spines, I agree with Raw (1925 p. 258) in presuming that these spines represent the intergenal spines rather than the genal spines. From Barrande's series it is not possible to determine the stage at which the intergenal spines were replaced by the genal spines. It is, however, to be remembered that in *Paradoxides* the change took place very rapidly through a few moults in the Meraspid Period.

Family *Olenidae* Burmeister.

Larval stages of Olenids have been described by a considerable number of writers. Most of the descriptions, however, comprise single specimens giving but little information on the general ontogenetic development of the species. Among Scandinavian writers might be mentioned Holtedahl (1910) and Poulsen (1923), the latter describing the ontogeny of *Peltura scarabæoides* (Wahlenberg). Special papers dealing with the ontogeny of the Olenidae have been published by Raw (1925) on *Leptoplastus salteri* (Callaway) and by Strand (1927) on *Olenus gibbosus* Wahlenberg. Kaufmann (1933) has described the ontogeny of *Olenus transversus* Linnarsson. In the following the larval development of the different genera is discussed and new studies on Protaspid stages of *Olenus* are presented.

Olenus. Strand (1927) has presented a careful description of the larval development of *Olenus gibbosus* Wahlenberg. He describes three different stages in the Protaspid Period, and it is his merit to have shown the presence of the "tapering ridges" in front of the eye ridges on either side of the frontal lobe of the glabella. Strand arrives at the conclusion that the anterior border of the cephalon is formed by the frontal lobe and the ridges proceeding from its anterior portion. More recently Kaufmann (1933) has described the ontogeny of the related species *O. transversus* from Scania. The development, illustrated by photographs (l. c. fig. 3), corresponds to that of *O. gibbosus,* except for the presence of a lateral marginal rim in the protaspis.

I have had the opportunity of studying the interesting material described by Strand. Among the type material now preserved in the Paleontological Museum, I have identified two more Protaspid stages in addition to the three described by Strand. The two new stages seem to complete a series of five succeeding stages, of which two belong to the Anaprotaspid Period and three to the Metaprotaspid Period. Text-figs. 9, a—e illustrate the five specimens of which those in 9 c and 9 e were figured by Strand (l. c. pl. figs. 2, 3), and 9 b replaces a similar stage figured by Strand (pl. fig. 1).

Although the preservation is very good, the protaspis specimens are so small that it is exceedingly difficult to obtain a correct impression of the finer structures in the dorsal shell. The present drawings were made by means of a drawing-apparatus, and carried out after a careful study in the binocular microscope under light from different angles. The faint furrows on the cheeks are difficult to distinguish except in certain angles of light. I have tried in vain to obtain good photographs of the small specimens.

1. The smallest specimen noticed (text-fig. 9 a) measures 0.33 mm in length. The shield has a circular outline and is not very strongly vaulted. The morphological characters are less distinct than in later stages. The glabella is well marked, but the axial furrows are shallow and the glabella does not reach the posterior border. In front the glabella increases in width, and projects into lateral tapering ridges from which it is not separated such as in later stages. The exact lateral extension of the tapering ridges are not possible to decide. The glabella is divided by four faint transverse furrows into five segments, of which the first one, the frontal lobe, is larger than the others which are of equal length, the occipital ring being apparently a little more narrow than the rest. The cheeks have faint indications of furrows forming a continuation of the glabellar furrows, and running across the cheeks forming an angle of about 60° with the axial furrows. The lines are slightly curved with the convex side forward, and the frontal lines more transverse than those in the posterior half of the shield. Only faint traces of eye ridges are developed. The eye ridges appear to be formed by the anterior half of the pleural portion of the antennal segment.

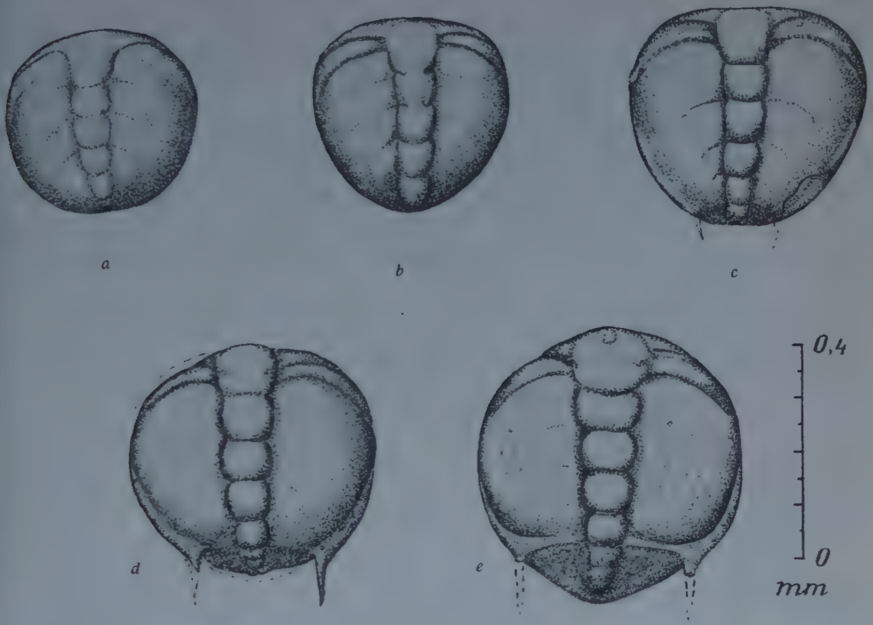


Fig. 9. Series of protaspides of *Olenus gibbosus* (Wahlenberg) from the Upper Cambrian of Ringsaker, Norway. 70×. Specimens collected by Strand, who has previously figured the specimens *c* and *e*. *a*—*b*=anaprotaspides, *c*—*e*=metaprotaspides. Nos. 30231a (*a*), 30231b (*b*), 30225 (*c*), 30265 (*e*), of Pal. Mus. Oslo Coll.

The described protaspis represents an early anaprotaspis. Among the primitive characters of this stage might be pointed out: the comparatively short glabella, the little differentiation of the frontal lobe, and the rudimentary eye ridges.

2. The second stage (text-fig. 9 b) measures 0.36 mm in length. It probably belongs to the same stage as the earliest protaspis described by Strand. Since the present specimen has a rounded posterior border, it might be possible that it belongs to a slightly younger stage but it does not seem likely.

The present stage is only approximately circular in outline. The anterior border is straightened out and the rest has a more parabolic outline. The surface is strongly arched, particularly the most posterior portion, which has the median portion bent down as indicated in the schematic drawing in text-fig. 10. The glabella is well marked, but not much vaulted in transverse direction such as in later stages. The glabella, extending to the posterior margin, contains five distinct segments of which the frontal lobe is larger than the others. The antelateral sides of the frontal lobe are somewhat steeper than the tapering ridges from which it therefore might be separated. The distinct tapering ridges, which we might interpret as belonging to the preantennal segment, diminish in width outwards, but reach almost to the broadest part of the shield. In contrast to the preceding stage the eye ridges are well developed, runnnig from the axial furrows at the middle of the frontal lobe, in an arc outwards to the margin at the broadest part of the shell. In Strand's drawing the eye ridges are depicted more as narrow rims with a flat area between them and the tapering ridges in front. From the present studies the frontal border of the eye ridges seems to decline more evenly down to the tapering ridges in front, thus leaving no space between. Distinct palpebral lobes along the lateral margin cannot be distinguished, but apparently the eye ridges pass gradually into these lobes.

As in the earliest stage the cheeks have faint oblique furrows passing from the glabellar furrows towards the margin. The posterior furrows form an angle of about 60° with the axial furrows, while the frontal pair, behind the antennal segment, forms an angle of about 70°. As discussed below, the oblique furrows evidently mark the division lines between succeeding segments in the head.

Both this and the preceding stage belong to the Anaprotaspid Period, on account of the presence of five segments in the axis, indicating five pairs of limb-bearing segments. The two described stages seem to suggest that the five segments were developed more or less simultaneously, the occipital segment not being added at a later stage than the others.

Characteristic of the last anaprotaspis are the more distinct glabellar furrows and the well developed eye ridges.

3. The third stage (text-fig. 9 c), which was described and figured by Strand (l. c. pl. fig. 2), has according to my measurements a length of 0.40 mm in dorsal projection. The shield is strongly vaulted, especially at the posterior border which is bent down almost vertically as indicated in text-fig. 10 c. The glabella is well marked by strong axial furrows. In addition to the five distinct segments of the glabella a new one is added at the posterior steep portion. The glabella is divided by strong transverse furrows, each segment being more

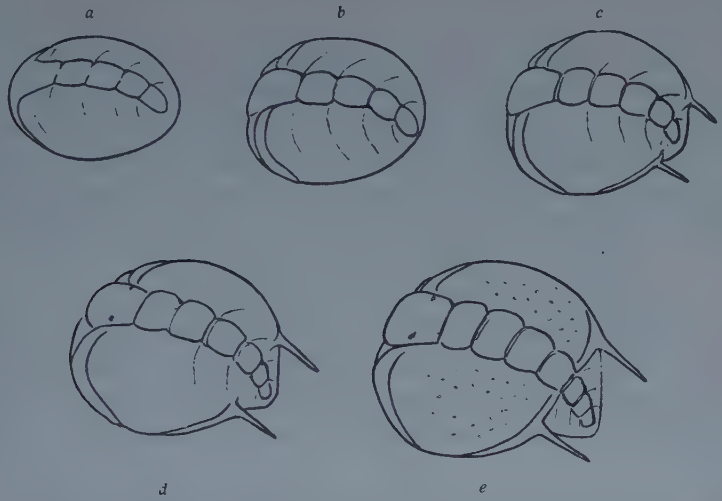


Fig. 10. Series of protaspides of *Olenus*. Semidiagrammatic drawings in dorso-lateral view. *a*—*b*=anaprotaspides, *c*—*e*=metaprotaspides (comp. text-fig. 9).

strongly vaulted than in the earliest stages, thus giving the axis its characteristic annulated appearance. The second to fourth segments of the glabella are mutually alike, while the frontal lobe is a little larger and the occipital ring somewhat more narrow. The frontal lobe is separated from the tapering ridges which are shorter than in the preceding stage, reaching but half the way to the lateral margin. The eye ridges are distinct with a sharper upper edge, which might give the impression of more isolated ridges such as indicated in Strand's drawing.

The cheeks, or pleural areas, have indications of oblique furrows of the same type as those of the earlier stages. Along the postlateral margin indications of a rim occur. The rim runs backwards to the hind border, where it projects into a small delicate spine directed backwards and downwards as indicated in text-fig. 10 c. The structures are too minute to show exactly from what point the spines project, but from a comparison with the two following stages, it seems probable that the spines are situated at the border between the preoccipital and occipital segments, according to the oblique furrows interpreted as segmentary division lines. In this case it is natural to assume that the spines represent true intergenal spines, being the distal points of the preoccipital pleuræ. Later stages show, as pointed out by Strand, that the spines develop into intergenal spines, but these stages do not demonstrate the connection with the axial segments.

The posterior portion forming the protopygidium is bent down mainly along a line running from the base of the intergenal spine towards the transverse furrow beyond the occipital ring.

The presence of an extra segment shows that the described protaspis represents Degree 1 of the Metaprotaspid Period. Characteristic features are, in addition to the new segment, the presence of intergenal spines and the faintly developed postlateral marginal rim.

4. The fourth stage in the series (text-fig. 9 d) measures 0.43 mm in length (dorsal projection). The cephalon has the same lenght, 0.38 mm, as in the previous stage, but this is partly due to a somewhat different angle of preservation. Also in the general morphological characters the present stage is not much different from the former.

The outline of the shield is almost circular, the surface a little less vaulted except for the hind portion which is directed downwards as shown in text-fig. 10 d. The glabella is a little broader than in the former stage and the frontal lobe less prominent. A new feature is the presence of a pair of small pits on the frontal lobe. These pits later develop into the foremost pair of glabellar furrows. The structures are quite similar to those found in early Meraspid stages of *Paradoxides* and possibly in the late anaprotaspis of *Blackvelderia*.

Behind the shorter tapering ridges the distinct eye ridges reach to the broadest portion of the cephalon. The cheecks are smooth with faint traces of oblique furrows in the posterior portion. Traces of two pairs of furrows might be recognized, the posterior ones leading from the occipital furrow outwards and backwards to the intergenal spine. There is good reason to believe that this line forms the border between the preoccipital and occipital segments. Behind this line another, more transverse line, marks an edge behind which the posterior portion of the protaspis is bent down (text-fig. 10 d). It seems very probable that this line marks the course of the later developing hinge-line or suture between the cephalon and transitory pygidium.

The postlateral rim is more distinct than in the previous stage. The rim decreases in width towards the broadest part of the cephalon. Posteriorly the rim projects into more powerful intergenal spines directed partly downwards as indicated in text-fig. 10 d. (The spine shown in text-fig. 9 d, was destroyed during the further preparation of the specimen.) According to their position in relation to the cheek furrows, the spines apparently belong to the preoccipital segment and thus represent true intergenal spines.

The protopygidium is not well exposed on account of its declined position. Two segments seem to be present in the axis. The described protaspis apparently represents Degree 2 of the Metaprotaspid Period.

Characteristic new features are the pits on the frontal lobe of the glabella, the stronger development of the intergenal spines and the rudimentary transverse hind border of the cephalon.

5. The fifth and latest protaspis observed (text-fig. 9 e) was also described and figured by Strand (l. c. pl. fig. 3 a, b). It measures 0.52 mm in length in dorsal projection with a cephalic length of 0.41 mm. The outline is subcircular with the posterior portion forming a triangle projecting between the intergenal spines. The surface of the cephalon is moderately convex. The five-segmented glabella has a well rounded frontal lobe, provided with lateral pits and a small circular depression in front which, however, might be accidental.

The tapering ridges representing the preantennal segment are shorter than in the previous stage. The eye ridges are distinct, but no special palpebral lobes are developed at their lateral terminations. The cheeks have no traces of oblique furrows, but the surface has numerous shallow pits similar to those found in later growth stages. Along the lateral margin the postlateral margin is well developed and projects into powerful intergenal spines which are now broken off in the specimen, but which are depicted in Strand's drawing (l. c. pl. fig. 3a). From the base of the intergenal spine the rim continues in median direction to the posterior portion of the occipital ring. The posterior border has the same position as the transverse line present in the preceding stage. This posterior border of the cephalon has practically attained the same structure as in the Meraspid stages. As shown in the previous stages, the transverse line or posterior border of the cephalon has a direction which differs decidedly from the course of the oblique furrows indicating the primary segmentation of the protaspis. It seems therefore probable, as was the case in *Pardoxides*, that the transverse hind border of the cephalon is a secondary formation crossing the original segmentation.

The protopygidium is strongly declined as indicated in text-fig. 10 e. The outline seems to be more triangular than indicated in Strand's drawing. The axis has three segments indicated, and it is therefore probable that the present stage belongs to Degree 3 of the Metaprotaspid Period.

Characteristic of the described stage is the appearance of a surface sculpture, and particularly the formation of a posterior rim or posterior border in the cephalon.

It is probable that the present stage forms the last protaspis in the ontogeny of *Olenus gibbosus.* The lenght of the cephalon of the earliest Meraspid stage figured by Strand (l. c. pl. fig. 4a,b) is namely only 0.03 mm. longer than in the last protaspis described. The described ontogenetic series of five succeeding protaspides therefore seems to be very complete, and probably forms the best early larval series hitherto known.

The development through the Meraspid Period is described and illustrated by Strand (l. c.), and one of his earliest stages is depicted in fig. 24 on pl. 1. The following major features in the development might be recognized. An anterior border is gradually formed by an anterior and lateral growth of the area in front of the glabella and eye ridges. This area corresponds to the preantennal segment, which in the early ontogenetic stages was presented by the tapering ridges primarily not separated from the frontal lobe of the glabella. The lateral pits on the frontal lobe are strongly developed in the early Meraspid stages such as in *Paradoxides*, but later become reduced. The intergenal spines are rapidly reduced at a cephalon length of 0.53 mm, corresponding to one of the earlier Degrees of the Meraspid Period.

The development of the facial suture is not clear, but, from the development of the postlateral rim, we might arrive at certain conclusions concerning its oirgin. In the last protaspis stages the postlateral rim extended forward to the broadest point of the cephalon. Through the Meraspid Period the frontal point of the rim in the cranidium gradually moves backwards towards the rudimentary intergenal spine. This means that the facial suture, or rather the posterior branch of it, migrated backwards towards the posterior margin. In the earlier Meraspid stages the suture evidently crossed the antelateral portion of the cephalon. We thus had a typical proparian head plan with the intergenal spine serving as genal spine such as pointed out by Poulsen, Raw, and Stubblefield. The free cheeks were evidently narrow sigmoid in shape. Judging from the structures in the protaspis stages, it seems reasonable to conclude that the suture at an early stage had a marginal course (a ventral one is less likely), occupying the frontal part of the protaspis as far as to the broadest part or the terminal points of the eye ridges.

Peltura. Poulsen (1923) has described and figured certain larval stages of *Peltura scarabæoides* (Wahlenberg) from the Upper Cambrian of Bornholm. The youngest stage has an axis of six segments according to the somewhat schematic illustration. This metaprotaspis has intergenal spines like *Olenus*, but differs in having a distinct marginal rim along the entire margin except in the protopygidium. An early Meraspid stage figured is of interest in showing the Proparian facial sutures crossing the antelateral corners of the cephalon. Through later stages the posterior branch of the facial suture migrates backwards towards the intergenal spine which becomes reduced.

Leptoplastus. A detailed description of the ontogeny of *Leptoplastus salteri* (Callaway) from the basal Ordovician in Shropshire, England, has been published by Raw (1925). The earliest stage at his disposal belongs, however, to the first Degree of the Meraspid Period. Raw's reconstruction of this stage is reproduced in fig. 31 on pl. 1. In his reconstruction the free cheeks are turned up into the horizontal plane, not much of them are visible in normal dorsal view.

The smallest stage found has not less than seven postcephalic segments, and therefore represents a comparatively late stage. In the cephalon both the genal and intergenal spines are about equally developed, and in addition to these a pair of procranidial spines are present which are situated at the front margin just inside the anterior branch of the facial suture. It is of interest to notice, with regard to the present studies, that the free cheeks with the genal spines are directed largely downwards so that the facial suture more or less had a marginal course, such as appears to be typical in earlier stages of other trilobites.

Triarthrus. Already in 1879 Walcott described the larval) development of *Triarthrus eatoni* (Hall) (described as *T. becki* Green from the Upper Ordovician of New York State (Walcott 1918, pl. 30, figs. 1—15). But no protaspis was known until Beecher (1893, 1895, pl. 8, figs. 12, 13) described two late protaspis stages and later Walcott (l. c. p. 143, pl. 30, fig. 16) found a similar form.

The two protaspides reproduced in figs. 32 and 33 on pl. 1 have an elliptical outline similar to that of *Liostracus* (text-fig. 8 b). In his first paper Beecher meant to recognize six annulations in the glabella, but in his later paper he points out that the normal number of five is present. The specimens are described as anaprotaspides, but the presence of a protopygidium of two or three segments shows that the specimens belong to Degree 2 or 3 of the Metaprotaspid Period. The protopygidium is marked off by a faint transverse line.

In contrast to other Olenid protaspides described, the preglabellar field of the preantennal segment is well developed already in these young stages. At the same time the drawings indicate that the eye ridges were very broad, and apparently comprised the entire width of the antennal segment such as in the Olenellidae.

Family *Asaphiscidae* Raymond.

From the Upper Cambrian of Alabama, U. S. A., Lalicker (1935) has recently described a series of larval stages probably belonging to the species *Blainia gregaria* Walcott. Lalicker arrives at conclusions which deviate considerably from the general conception elsewhere obtained. Raymond (1935) finds the results to favour Beecher's view that the "Hypoparia" were primarily blind forms. Stubblefield (1936, p. 427, footnote) regards the results presented by Lalicker as due to a possible misinterpretation of the structures, or based on inadequate data. I have not personally seen the material, but, judging from the drawings, I am inclined to believe that the facial suture claimed to be found already in the earliest (protaspis) stage might be a transverse furrow only.

Lalicker describes and figures six or seven protaspis stages, but at least two of them (l. c. figs. 4, 5) seems to belong to the same stage, and a late stage (fig. 7) might only with doubt be referred to the Protaspis Period. Figs. 13—18 on pl. 1 illustrate the probable stages represented. The two first stages (13, 14) apparently belong to succeeding stages of anaprotaspides. The shell is vaulted with a circular outline except for a small posterior reentrant in the last stage. The glabella lacks transverse furrows, and the anterior part of the frontal lobe projects into lateral tapering ridges similar to those in *Olenus*, and therefore signifying a preantennal segment rather than a "larval ridge" belonging to the antennal segment. Lalicker states that faint eye ridges and palpebral lobes are present already in the earliest stages, but from the drawings it appears that eye ridges are absent even in more grown-up stages, and in the youngest stages they must have been very faint.

Lalicker claims to find facial sutures already in the earliest stages, where they are "obscurely developed". In later protaspis stages the suture is said to follow the lateral border of the frontal lobe as far as to the eye ridges, which it follows to the lateral margin of the cheek. The suture thus conforms with the furrow bordering the glabella and the eye ridges, and this might raise a certain suspicion as to the actual presence of a true suture in these small specimens. On the other hand the drawings indicate that the eyes have a distinct intramarginal position already in the Metaprotaspid stages. Through the Metaprotaspid Period the eyes migrate inwards from their almost marginal position at the antelateral corners of the cephalon. If the presence of eyes can be demonstrated with certainty in these small stages, one might assume that a facial suture had migrated in from the margin already at this larval stage.

In figs. 13—18 on the plate the different larvæ described by Lalicker are referred to their respective stages of development. The accurate stage of the Meraspid cephalon (fig. 18) is not possible to decide.

Family *Proetidae* Corda.

To the genus *Proetus* Beecher (1895, pl. 9, figs. 5, 6) referred two protaspis specimens from the Upper Ordovician of New York State, U. S. A. The larger of the two is shown in fig. 34 of pl. 1. A similar protaspis was figured by Troedsson (1918, pl. 1, fig. 25) from corresponding beds in Scania, Sweden. Both the American and Swedish specimens were described as anaprotaspides. The presence of several postcephalic segments, however, shows clearly that they belong to the Metaprotaspid Period, the figured specimen (pg. 34) apparently representing Degree 4.

Characteristic of the metaprotaspis is the more or less circular outline, the narrow five-segmented glabella and the large eyes which have an antemarginal position. The large eyes evidently migrate backwards during the further development, and probably there existed a period of Proparian course of the facial suture. The protopygidium has, according to the published drawings, both pleural and intermediate furrows. This might indicate that the lay-outs of the division into separate thoracic segments are indicated already in the late Metaprotaspis.

Family *Calymenidae* H. M. Edwards.

Calymene. From the Upper Ordovician beds of New York State, U. S. A., Ruedemann (1912, pl. 9, fig. 7) has described a large protaspis (pl. 1, fig. 35) which he refers to *Calymene senaria* Conrad var. He points out the great resemblance to the protaspis of *Proetus* above described. The drawing is somewhat schematic, but it apparently reveals the most characteristic features. With a length of 1.30 mm the protaspis attains a considerable size. In the five-segmented glabella the third segment is greater than the others, but this might be due to incomplete preservation. The eyes (or rudiments of them) have an antemarginal position just as in *Proetus* and in *Dalmanitina.* The latter genus remain Proparian while Calymene, though referred to the proparian trilobites by American authors, might belong to the opisthoparians (comp. Stubblefield, 1936, p. 429).

The protopygidium apparently contains not less than eight segments, indicating that the present specimen represents Degree 8 of the Metaprotaspid Period. At this stage of development most other trilobites were far advancid into the Meraspid Period. The formation of a transverse suture is thus delayed in this genus, although rudimentary division lines are suggested by the furrows between the pleural furrows.

Pharostoma. From the Upper Ordovician Leptæna Limestone Warburg (1925, pl. 4, fig. 9) figures a young larva of *Pharostoma leptænarum* Törnquist measuring 0.95 mm in length. According to the description the larva has one free thoracic segment thus belonging to Degree 1 of the Meraspid Period. Of particular interest is the presence of facial sutures crossing the lateral border at the genal angle. (Warburg mentions that the lateral eyes have a more antelateral position than indicated in the drawing.) Apparently only five postcephalic segments are present indicating that the larva belongs to Degree 5, i. e. the Meraspid Period was introduced much earlier than in the larva referred to *Calymene senaria* Conrad.

Family *Odontopleuridae* Burmeister.

Beecher (1895, pl. 9, fig. 1) describes and figures a metaprotaspis of *Acidaspis tuberculata* Conrad (pl. 1, fig. 39) from the Lower Devonian of Albany, New York State, U. S. A. With its two (?) postcephalic segments the metaprotaspis of 0.9 mm length appears to belong to Degrer 2. In spite of its numerous spines the general characters are similar to those found in other trilobite larvæ, except for the small lateral elevations interpreted by Beecher as lateral eyes. It seems possible, however, that these structures also might be mere sculpture like the rest of the points and spines. The postlateral spines probably represent the intergenal spines.

The protopygidium is strongly declined as shown in Beecher's profile drawing and is thus similar to *Olenus*.

Beecher (1895, l. c. pl. 9, fig. 4) also described the species *Corydocephalus consanguinensis* (Clarke) from the same beds. The metaprotaspis probably represents Degree 4 on account of the four pairs of spines in the protopygidium (pl. 1, fig. 40). The cephalon is exceptionally broad, but resembles in general characters the similar stage of *Dalmanitina*. The postlateral spines are apparently intergenal spines. Also in this species small lateral eyes are indicated, but it seems possible that in this case also they might have been tubercles only.

Family *Asaphidae* Burmeister.

Unfortunately little is known of the early larval stages of Asaphidae and other larger Post-Cambrian trilobites. Raymond (1914 b) described Meraspid stages of the Ordovician *Isotelus gigas* De Kay from Trenton Falls, New York State, U. S. A. The large pygidium of the earliest stage (Degree 3) suggests that the last metaprotaspis must have had a comparatively large protopygidium, indicating a considerable Metaprotaspid Period such as in *Calymene*.

GENERAL RESULTS

The Structure of the Protaspis.

After having presented our present knowledge on trilobite ontogeny, we shall attempt to arrive at a general conception of the structure of the trilobite protaspis. Our present rather comprehensive knowledge of the protaspis permits us to draw certain conclusions regarding the homology of the structures within different groups, and to suggest an interpretation of the segmentation expressed in the protaspis.

Pl. 1 illustrates the more important protaspis series depicted in the same size. At first sight the protaspis stages of different forms differ considerably both in size and structure.

Concerning the size it appears that the smallest protaspis known measures 0.24 mm (*Shumardia*, fig. 43), and since earlier stages might be expected in this form, the smallest protaspis might have had a length down to about 0.2 mm. The largest protaspis (*Calymene*, fig. 35) measures 1.3 mm, but there seems to be reason to believe that protaspides of large asaphides such as *Isotelus* might have been bigger. The size of the protaspis seems largely to correspond to the size of the adult. Large forms such as *Paradoxides* have protaspides of greater size than those of small species such as *Olenus* and *Shumardia.* But on the other hand species of the early Olenellida seem to have a relatively large protaspis compared with later forms i. e. *Dalmanitina.* The early Meraspid stages of Trinucleidae and Agnostidae also indicate comparatively large protaspides. It is not possible to trace a definite connection between the size and the phylogeny, although the more primitive forms according to my interpretation, (comp. p. 150) seem to have a comparatively large protaspis in relation to the adult. (*Acidaspis* forms an exception.)

Since the larval development of the trilobite takes place through ecdysis, one would expect that each stage corresponded to a certain size group. In fact this is demonstrated in the early Meraspid Period of *Tretaspis* (Størmer 1930, text-fig. 28). A similar measurement of the Protaspid stages is difficult to carry out chiefly on account of the small number of specimens generally available, and because of the convexity of the shields. Yet the series of *Olenus* (text-fig. 9) indicates successive stages in size.

Concerning the structure of the dorsal shell, the protaspides of the many different genera all have a circular or ovate shield which might be provided with spines. Distinct spines usually do not appear until later Protaspid stages. It is interesting to notice that in the development of the larva the spines have a tendency to develop at a length of the dorsal shell of about 1 mm. The spines are most characteristic of the Meraspid Period, but occur also in the later part of the Protaspid Period. The spines comprise the procranidial, genal, intergenal and occipital as well as the pleural spines. In *Acidaspis* additional short marginal spines are present. Procranidial spines have never been found in the protaspis. The conditions in the protaspis thus give no support to the hypothesis of Raw (p. 65) on the presence of a seven-spined early phylogenetic stage in the larval development of the Trilobita. Our present knowledge on trilobite ontogeny speaks in favour of regarding the development of spines chiefly as an adaption to a pelagic mode of life. Similar views have been expressed by several earlier writers. Analogous adaptions are found in numerous pelagic larvæ of different invertebrate groups. The development of floating structures runs parallel to the increase in size. The development and homology of the trilobite spines are discussed below.

The trilobite larva apparently hatched from small spherical or elongate eggs measuring less than 0.2—0.5 mm in length. The eggs might have been kept afloat in the water layers or were lying on the bottom. Structures interpreted as trilobite eggs have been described by Billings (1870), Barrande (1872, pl. 11, fig. 6), and Walcott (1880—81). Raymond (1931, p. 172) states that the structures have not been proved to be trilobite eggs, but recently Schulze (1936) has pointed out that the position of the eggs on the glabella of the trilobite described by Barrande corresponds closely with the position of the eggs in recent Ixodidae. The exact nature of the fossil structures is not clear. Dr. R. Macdonald has suggested to me that the small bodies described by Walcott might have been foecal pellets similar to those occurring in abundance on the bottom of the present seas. Since the trilobite eggs apparently had some kind of shell, it seems, however, not impossible that the favourably preserved structures described by Barrande and Walcott actually might represent the remains of trilobite eggs.

During the Protaspid Period the dorsal shield undergoes distinct changes in its morphological characters. Most significant is the addition of new segments in the axis. While the earliest stages have only five segments expressed in the axis, the later ones have six or more. In the later stages one extra segment is apparently added in each new stage, but ecdysis might also have taken place within each well-defined stage as indicated in *Shumardia*. The present studies have shown that in the earlier Protaspid stages the number of segments is constant, and the different stages therefore have to be distinguished by the size and by distinct morphological characters. The characteristic five-lobed axis appears to be a primary feature which is expressed as soon as the dorsal morphological features have become more distinct. As pointed out in the chapter on segmentation, the five-lobed axis evidently signifies a primary segmentation the layouts of which are different from the teloblastic secondary segments.

For these reasons it seems natural to divide the Protaspid Period of the trilobite ontogeny into two subperiods. Beecher indicated that the protaspis might include ana-, meta-, and paraprotaspides, but he gives no definition of these stages and they have been used without regard to the degree of segmentation. Since certain terms have been applied by Beecher, I propose to maintain two of his terms which are here defined.

1. The Anaprotaspid Period. The early Protaspid Period comprising only primary somites, axis with five segments.
2. The Metaprotaspid Period. The late Protaspid Period comprising both primary and secondary somites, axis with more than five segments, primary somites forming the cephalon, secondary somites the protopygidium.

The early protaspis might consequently be called the anaprotaspis and the later one the metaprotaspis.

On pl. 1 the different Protaspid stage are arranged according to the present division. Within the Anaprotaspid Period the stages of different species are not so easily compared, but in the Metaprotaspid Period stages with the same number of somites are placed in a common vertical column. It appears from the plate that Anaprotaspid stages are lacking in many forms (none were described by Beecher). This might be due to an incomplete fossil record, but on the other hand certain features might suggest also another explanation. In *Sao* the youngest known larva (pl. 1, fig. 27) has very indistinct dorsal features although it apparently belongs to the Metaprotaspid Period. In *Paedeumias* (pl. 1, fig. 1) and *Blainia* (pl. 1, figs. 13, 14) a similar lack of annulation of the glabella is significant of the Anaprotaspid or early Anaprotaspid Period. It seems therefore very possible, as indicated also by Beecher, that the different trilobites hatched at different stages of development just as other groups of Arthropoda e. g. the Crustacea. The Anaprotaspid Period, or a great part of it, might have been accomplished within the egg in more advanced forms. It might even be expected that parts of the Metaprotaspid Period might have been reached before hatching in some of the highest trilobites. In fact the Anaprotaspid stages are only known in the more primitive trilobites belonging to the Protoparia and Opisthoparia, and the finds are restricted to the Cambrian.

The Anaprotaspid Period.

This early larval period has become better known in recent years. In several opisthoparian species it has been possible to distinguish more than one separate stage. Pl. 1 illustrates some of the more typical species. It appears from the plate that anaprotaspides are known only among the Protoparia and Opisthoparia. Since the earliest larvæ are best known in the latter group, this will be dealt with first.

Order Opisthoparia. Among the very young trilobite larvæ described, the earliest stage of the Middle Cambrian *Blackwelderia* (pl. 1, fig. 10) appears to be the most primitive or most recently hatched. In the published drawing, which, however, is fairly schematic, a pair of short axial furrows in the middle of the convex shield is the only morphological character visible. In a more advanced stage (pl,1, fig. 11) the glabella has attained its full length and three transverse furrows are indicated. The length of the posterior lobe indicated that this includes two segments thus giving a total number of five segments in the axis. The next stage is well developed with the dorsal characters very distinct.

Early Anaprotaspid stages might also be studied in the ontogenetic series of *Olenus* (text-fig. 9 and pl. 1, figs. 19, 20) and *Blainia* (pl. 1, figs. 13, 14). The earliest stage in both species might correspond to the second stage in *Blackwelderia.* The circular shield is not very much vaulted, and the dorsal features are but feebly marked. The shallow axial furrows border the glabella, which might either lack the glabellar furrows or they might be present as four faint furrows across the glabella. In the earliest stage the glabella does not reach the posterior margin. The frontal lobe of the glabella is not bordered in front and projects laterally into tapering ridges forming the anterior border of the shield. The eye eye ridges are but faintly developed. Their strong development in a similar stage in *Olenopsis* (pl. 1, fig. 25) might be doubtful since the drawing seems little reliable.

The last anaprotaspid stage is well studied in many species. The shield has become more convex, and this seems partly due to an increase in the length of the glabella which now reaches the posterior margin. The glabella is more convex than in the previous stage, and the four transverse furrows are generally very distinct, separating the five glabellar lobes. The four posterior lobes are mutually much alike, the posterior one has not the character of a telson. The frontal lobe is generally slightly bigger than the others. *In Paradoxides* (text-fig. 7; pl. 1, fig. 5) the lobe is divided by a median furrow, but this is apparently a special characteristic of the genus. In *Blackwelderia* the frontal lobe has indications of small lateral pits, which probably are homologous with the antennuary pits developing in later larval stages of other genera. When the glabella becomes more vaulted, the frontal lobe is separated from the tapering ridges (the area in front of the eye ridges). The tapering ridges outside the glabella form the preglabellar field or preantennal segment. In *Olenus* the preantennal segment is little exposed, and in *Blainia* it is not shown in the drawings. The narrow field is easily overlooked and, before it was demonstrated by Strand, the eye ridges or "larval ridge" (Warburg) were regarded as forming the anterior border. In the more primitive *Paradoxides* the preantennal segment is visible not only in front of the eye ridges but also in front of the glabella. The same is indicated in *Liostracus* (?) (text-fig. 8) and *Triarthrus* (pl. 1, fig. 32, 33).

The pleural portion beyond the preantennal segment is strongly vaulted in the last Anaprotaspid stage. Certain forms such as *Olenus* and *Olenopsis* show an interesting segmentation of the pleural area. Faint oblique furrows form a lateral continuation of the glabellar furrows. The frontal pleura behind the preantennal segment develops differently from the posterior ones. The earliest stage of *Olenus* shows how the eye ridges develop in the anterior portion of the segment. This shows that the eye ridges, leading into the palpebral lobes, represent only a part of the pleuræ of the antennal segment.

In the Middle Cambrian genera, *Paradoxides*, *Blackwelderia* and *Olenopsis*, the eye ridges and palpebral lobes reach the posterior border. The palpebral lobes form narrow marginal rims embracing the cheeks.

Order Protoparia. Anaprotaspid stages of Olenellidae (=Mesonacidae) are known in several different genera. The most primitive stage described is evidently an early anaprotaspis of *Paedeumias* (text-fig. 5 a; pl. 1, fig. 1). The strongly vaulted shield has a well marked, broad and unsegmented glabella, reaching from the hind margin forwards to a point well beyond the frontal margin. Distinct eye lobes project from the frontal portion of the glabella and extend almost to the hind margin. A preglabellar area or preantennal segment is well developed in front of the glabella and the eye lobes, and continues also backwards outside the palpebral lobes.

A somewhat later stage is demonstrated in a protaspis of *Elliptocephala* (text-fig. 5 b; pl. 1, fig. 2). In the plate it is referred with doubt to the last anaprotaspis, but it might belong to an earlier stage.

Another specimen, which is of about the same size (text-fig. 5 c), has more distinct structures in the frontal portion.

In the anaprotaspis of the Olenellidae the glabella has distinct axial furrows except in front where the frontal lobe is not separated from the eye lobes. In the earliest stage of *Elliptocephala* the frontal lobe is not well separated from the preglabellar field, but this might be due to the mode of illustration, and other anaprotaspides have the glabella well bordered in front. The first transverse furrow of the glabella is absent in *Elliptocephala*, but is seen in *Paedeumias*. The shape of the frontal lobe in later stages of *Elliptocephala* (text-fig. 5 d; pl. 1, fig. 3) shows clearly that also in the anaprotaspis the glabella included five segments, the two anterior ones not being separated by a transverse furrow.

A well developed preglabellar field or preantennal segment is found in the anaprotaspis of the Olenellidae. As mentioned above it reaches as far as to the hind margin, and thus surrounds the complete central portion of the shield.

Beyond the preantennal segment the pleural portion is segmented by transverse or curved furrows forming continuations of the glabellar furrows. The anterior pleura forms the eye lobe which thus differs from the eye ridge occupying only a part of the pleura. Powerful intergenal spines project from the preoccipital segment.

A comparison of the anaprotaspides of Protoparia and Opisthoparia. At first sight the young protaspides of the two groups differ considerably. In the Opisthoparia the narrow glabella usually reaches the anterior margin, and only a narrow preantennal segment is visible in front of the eye ridges and palpebral lobes forming the lateral borders of the shield. In the Protoparia the glabella does not reach the anterior margin, and an extensive preantennal segment is found also lateral to the eye lobes. Intergenal spines are developed in the anaprotaspis.

Warburg (1925, p. 28) compares the protaspis of the two group and arrives at the conclusion that they agree largely with one another. The comparison is however, partly based on an incomplete knowledge of the anterior portion of the opisthoparian protaspis.

In spite of certain differences, however, the anaprotaspis of the two groups agree in the major characteristics. The glabella has five segments (some part of the preantennal segment might gradually be included in the frontal lobe), the palpebral lobes belong to the segment of the frontal lobe of the glabella i. e. to the antennal segment, a preantennal segment occurs in front of the glabella (or is partly included in it), and the pleural portion is segmented in accordance with the glabella. The comparison shows that the early protaspides of different trilobite groups agree in the essential characters; the differences observed are chiefly due to a different development of the preglabellar field or preantennal segment, and of the intergenal spines.

Anaprotaspides are not known in the Proparia and ? Hypoparia, but certain characteristics might be deduced from the metaprotaspis of these forms. In the Proparia the preglabellar field was hardly developed on the dorsal side. In the other group, on the other hand, there is reason to believe that an extensive preantennal segment was present.

The Metaprotaspid Period.

As stated above the present period is distinguished by the successive additon of new secondary segments in the protaspis. The larva remains a protaspis as long as the protopygidium has not become moveable against the cephalon. The length of the period is very different within different trilobite groups. Simultaneously with the increase in size and the addition of new segments several characteristic morphological features develop, partly as larval adaptions and partly as preparations to structures characteristic of later growth stages and of the adult trilobite.

The addition of new segments might be well studied in the probably fairly complete ontogenetic series of *Olenus*. The first Metaprotaspid stage has a slight reentrant at the hind border. As shown in the semi-diagrammatic drawing in text-fig. 10 the reentrant is formed by a bending downwards of the postmedian portion of the shell. At the same time a new segment is added to the five-lobed axis of the anaprotaspis. Apparently one segment is added at each ecdysis, but the possibility cannot be excluded that further ecdysis take place such as in Meraspid stages of *Shumardia* (Stubblefield, 1926). During further stages new segments are added forming the protopygidium. While the axis of the cephalon is considerably convex, the axis of the protopygidium is more straight, but it is bent down almost vertically so that the segments are seen only with some difficulty in dorsal view. The strong bending down of the protopygidium suggests that the dorsal side of the protoaspis grows more rapidly than the ventral side. The new segments are not curved in transverse direction such as the cephalon. The pleural furrows of the protopygidium are not distinct in *Olenus.* In *Elliptocephala* (pl. 1, fig. 3) even the axis is not distinct according to the published figure. In other forms such as *Paradoxides*, *Sao*, and *Dalmanitina* the pleural structures are more expressed. Both pleural furrows and transverse lines suggesting the borders of future thoracic segments are present.

During the Metaprotaspid Period certain morphological changes take place in the cephalon. In the last stage of *Olenus* the frontal lobe of the glabella is provided with a pair of small lateral pits. Similar structures might have been present already in the last anaprotaspis of *Blackwelderia*, and appear in the early Meraspid Period of *Paradoxides* and several other trilobites. On account of their appearance decidedly after the five-lobed glabella is established, it seems safe to conclude as indicated by Beecher (1895), that the pits have nothing to do with the primary segmentation of the glabella, but represent muscular apodemes apparently in connection with the antennæ as suggested below. During the Meraspid Period, however, the pits might increase in size and even unite across the glabella just as the true glabellar furrows (text-fig. 7e). In certain primitive trilobites such as *Callavia*, the antennuary pits remain as "glabellar furrows" in the adults.

In the pleural areas of the cephalon the primary segmentation, expressed by the oblique furrows, becomes obsolete. In *Olenus* the shell atains a pitted sculpture (apparently in order to support the thin shell as demontrated by Richter in adult forms). In *Acidaspis* and *Corydocephalus* (pl. 1, figs. 39, 40) the cheeks are provided with short spines.

The development of the eyes and the facial sutures are treated in a special chapter below. In the Olenellidae distinct eye-lobes are present, but a distinct palpebral lobe and a visual surface seem hardly to have been developed in the protaspis (*Holmia*). A rudimentary palpebral lobe is present in *Paradoxides*, but the presence of a functional lateral eye is not indicated. Indications of eyes are neither found at the distal points of the eye-ridges in *Olenus* and *Sao*. Lalicker (1935) claims to have found palpebral lobes and facial sutures in the metaprotaspis of *Blainia* (?), but their presence might possibly be due to misinterpretations. As pointed out by Beecher and others, the eye-ridges are characteristic of more primitive trilobite larvæ. It is absent in more advanced Ordovican forms such as *Proetus*, *Calymene*, and *Dalmanitina*, the latter belonging to the Proparia. Both in the Proparia and Opisthoparia the rudimentary lateral eyes have a marginal position. In the Olenellidae (Protoparia) on the other hand the rudimentary eyes are distincly intramarginal and the same appears to be the case in the Trinucleidae (? Hypoparia) of which the first Meraspid stage is the earliest larva known.

During the late Metaprotaspid Period the hind border of the cephalon is prepared. The formation of the hinge-line between the cephalon and the transitory pygidium is dealt with in a special chapter below.

Of particular interest is the formation of spines during the Metaprotaspid Period. The ontogenetic development of the different marginal spines is of primary importance to the study of homologies in the spines and sutures in the cephalon of the adult trilobite. In recent years the nature of the cephalic spines has been subject to considerable discussion among writers on trilobite morphology (comp. p. 65).

In the trilobite larva five kinds of spines might be distinguished (sculptural short spines such as in *Acidaspis* are not included).

1. Procranidial spine.
2. Genal spine.
3. Intergenal spine.
4. Occipital or nuçhal spine.
5. Postcephalic pleural spines.

Of these the procranidial (1) and the occipital (4) spine develop after the Protaspid Period. They are not common and might be seen in Meraspid stages of *Leptoplastus* (pl. 1, fig. 31).

The intergenal spine. This structure appears very early in the trilobite ontogeny. The nature of the spine has been much discussed, and conflicting opinions on the subject have caused considerable difficulties in the general conception of the cephalic segmentation. Recent and present studies give new evidence towards a general interpretation of these important structures.

As mentioned above the intergenal spines are well developed already in the anaprotaspis of the Olenellidae. In *Paedeumias* (or *Olenellus*) (Walcott 1910, pl. 25, fig. 22) the intergenal spines are nearly as long as the diameter of the protaspis. It is evident that the intergenal spines of the Olenellidae belong to the preoccipital segment. It is possible that some parts of the more frontal segments might take part in the formation of them. As mentioned below the genal spine in the metaprotaspis apparently is released from the intergenal spine, which therefore seems to have included the former. The pleuræ and the antennal and second leg-segments might also have joined, but the major portion of the intergenal spine of the Olenellidae belong to the preoccipital segment.

Among the Opisthoparia the larva of *Paradoxides* has well developed intergenal spines. The homologies of the spines have been much discussed. The new description of the larvæ of Bohemian species by Šuf (1926) left the impression that the spines belonged to the occipital segment and thus deviated from those in the Olenellidae. On account of the abnormal development of the glabella the structures are not clear and might easily be confused. Valuable new information was obtained by the recent studies of Westergård (1936) on Shwedish *Paradoxides.* The larvæ, which show no abnormal expansion of the glabella, have intergenal spines which, according to the published drawings and from verbal information obtained from Westergård, "with fairly great probability" project from the preoccipital segment of the glabella. Judging from the published illustrations it seems hardly possible to arrive at another conclusion.

Intergenal spines have been demonstrated in larval stages in numerous opisthoparian trilobites. The present studies of *Olenus* (text-fig. 9, 10; pl. 1, figs. 19—24) indicate that also in this genus the intergenal spine probably projects from the preoccipital segment such as in the Olenellidae and Paradoxidae.

One arrives at the conclusion that within different groups of the Trilobita the intergenal spines evidently are homologous structures, representing the prolonged pleural spines of the preoccipital segment. In the Trilobita the pleural spines of the preoccipital segment are stronger developed than the corresponding spines of the segment in front. In the protoparians the intergenal spines develop very early in the Protaspid Period. In the opisthoparians and proparians (?) the intergenal spines are noticed in the Metaprotaspid Period and thus having a somewhat later development. In the Hypoparia (?) (*Tretaspis*) the strong larval spines probably represent the genal spines and the intergenal spines are not noticeable.

During the Meraspid Period the intergenal spines are in general rapidly reduced and replaced by the genal spines. This is the case in the opisthoparians and the protoparians (Olenellidae), but in the latter the reduced spines are preserved also in the adults (pl. 2, figs. 3—5). As pointed out by various authors the intergenal spines remain as "genal spine" in the proparians. In the ontogeny of *Dalmanitina* (pl. 1, figs. 36—38) the spines are strongly developed in the Metaprotaspid Period. As an exception both intergenal and genal spines might be present in certain trilobites such as *Proboloides pessulus* Clark (comp. Kobayashi 1935 text-fig. 6).

The genal spine. The development of these spines might also be studied in the Metaprotaspid and early Meraspid Periods. In the Olenellidae it is probable, as pointed out by Ford, Walcott, and others, that the intergenal and genal spine are fused together in the Protaspid Period and that the genal spine is gradually released and migrates outwards (pl. 1, figs. 3, 4). Among the opisthoparians the genal spines are rarely preserved in the young larval stages on account of their more ventral direction as pointed out by Raw. In a late metaprotaspis of *Paradoxides* (text-fig. 7; pl. 1, fig. 7) the genal spine have a lateral position originating just below the rudimentary palpebral lobes. A particular development of the genal spines is found in the larva of the Cryptolithidae. The first Meraspid stage (text-fig. 6; pl. 1, fig. 41) has long spines which show that they must have been well developed already in the Protaspid Period.

Concerning the nature of the cephalic spines, Raw has recently presented a new hypothesis which has been discussed in detail above (p. 65). It appears from this discussion that the present studies hardly seem to give any support to his views.

The duration of the Metaprotaspid Period is different within different groups of trilobites. The number of segments in the axis minus five gives the minimum number of ecdysis. In pl. 1 a vertical line indicates the division between the Metaprotaspid and Meraspid Period. Among the Cambrian species only two or three Metaprotaspis stages are found. This means that the Meraspid Period is rapidly reached. Among the Ordovician genera certain forms such as *Shumardia* and *Tretaspis* have few stages, while more advanced genera such as *Proetus*, *Dalmanitina*, and *Calymene* have a longer Metaprotaspid Period, in the last genus comprising at least nine ecdysis. (In the related genus *Pharostoma* the number was apparently only four, indicating considerable variation.)

A short Metaprotaspid Period indicates that the larva soon obtained an open suture between the cephalon and the protopygidium, and this means that the larva rapidly attained a greater moveability and more rapidly attained the characters characteristic of the adult trilobites.

The presents studies of the protaspis might suggest a modification of the diagnosis presented by Beecher (p. 53) of the Protaspis:

> Minute circular or ovate dorsal shield with a length from 0.2—1.3 mm; dorsal shield without transverse suture separating cephalon and abdomen; axis distinct and strongly annulated except in youngest stages; rudimentary eyes intramarginal in Protoparia and Hypoparia (?) and marginal in Proparia and Opisthoparia. Anaprotaspis with five-lobed axis forming primary limb-bearing somites of cephalon. Metaprotaspis with postcephalic secondary somites forming a protopygidium.

The Segmentation of the Cephalon in the Protaspis and in the adult Trilobites.

Previous Conception of Cephalic Segmentation in Trilobites.

Although this problem has been touched upon on numerous occasions in the extensive trilobite literature, more detailed investigations and discussions on the subject are scarce. Different opinions have been presented, but they are in general to a great extent influenced by the assumption of a crustacean nature of the trilobites.

It was the descriptions of the young larvæ of Olenellids, and particularly the discovery of well preserved appendages in *Triarthrus*, that made possible a special study of the segmentation of the trilobite cephalon. Bernard (1894) discussed the segmentation in the protaspis of *Elliptocephalus*, and arrived largely to a correct conception of the fusion of succeeding segments, the pleuræ of which form the cheeks of the cephalon. He reckoned with four segments behind the first one which, with its lateral projections due to the bending round of the segment, had caused a metameric repetition in the succeeding four segments. The last occipital segment is, however, expected to have been incorporated at a later stage as claimed also by several recent authors. Judging from the variation in the number of glabellar furrows in adult forms, he erroneously deduced that the number of cephalic segments differed in different trilobite groups.

In his paper on trilobite larvæ Beecher (1895) points out that throughout the larval period the axis of the cephalon has five segments; when an additional pair of glabellar furrows is present it is not an indication of an additional pair of limbs, but is due to a secondary division of the frontal lobe of the glabella. The free cheeks are supposed to be the pleuræ of an ocular segment otherwise lost.

Jaekel (1901) interpreted the hypostoma as the first cephalic segment and the free cheeks including the rostrum as the second. The antennules were presumed to have been reduced.

Walcott (1910, p. 237—238) discusses the cephalic segmentation and arrives at the conclusion that the trilobite cephalon contains six or seven clearly defined segments.

1. Anterior border segment, the reflected margin of which supports the hypostoma.
2. Ocular segment carrying the visual surface of the eye.
3. Palpebral or first glabellar segment.

4—6. Second to fourth glabellar segments, the latter may be continued as an intergenal spine.

7. Occipital segment.

When Walcott mentioned six or seven segments, he was apparently in doubt concerning the presence of the first segment. The presence of a preocular segment is found "not improbable" on account of the procranidial spines in the larva of *Olenellus gilberti* Meek and *Olenelloides*, and because of two pairs of glabellar furrows in front of the palpebral ridge in *Callavia*. The ocular segment is said to include the anterior portion of the frontal lobe of the glabella.

In a later paper (1918, p. 126) Walcott omits the anterior border segment, but apparently on account of a "six-lobed glabella" in some species erroneously introduces four instead of three glabellar segments between the palpebral segment and the occipital segment. With the ocular segment in front he counts seven segments.

From his detailed studies on *Holmia* and *Kjerulfia* Kiær (1916, p. 83) was inclined to interpret the rostrum as a special segment in front of the ocular segment. Raymond (1917, p. 207) claims six segments in the cephalon of the Olenellid protaspis. Swinnerton (1919) points out strongly that in all trilobites the eye-lobes or eye-lines which are related to the palpebral segment always belong to the fifth segment reckoned from the posterior margin.

A more extensive and important discussion on the cephalic structures in trilobites is presented by Warburg (1925). The author largely bases her conclusions on Walcott's researches, and states that these "seem to have proved that the trilobites were closely related to the crustaceans". In accordance with this view the trilobite head is supposed to have had the following segments and appendages.

1. Ocular segment with antennule (antenna in trilobite).
2. Palpebral segment with antenna (reduced in trilobite).
3—6. Second to fifth glabellar segments with biramous appendages.

Concerning an extra preocular segment represented by the rostrum, Warburg (l. c. p. 41) finds this less probable. As assumed already by Kingsley (1897) the antenna (A_2) is regarded as being reduced. The occipital segment is presumed to have been incorporated at a later growth-stage and thus corresponds to the maxilliped segment in the crustaceans. The interpretation of the antennules as belonging to the ocular segment is hardly right, as pointed out by Schulze (1936, p. 193), since this segment of the acron has no appendages.

Henriksen (1926) has published a special paper on "The Segmentation of the Trilobite Head". His views chiefly follow those of the previous authors, and like Warburg he assumes that the trilobite possessed a crustacean head-plan with originally six pairs of appendages, but he regards the antennules as belonging to the palpebral segment. In the protaspis with its five-lobed glabella he finds no A_2 segment, and assumes that the second pair became reduced in most trilobites just as in recent copepods. As a support to his belief that the A_2 segment might have disappeared in some forms only he mentioned the six-lobed glabella of *Callavia* He is apparently not aware that the extra lobe is formed by a later division of the frontal lobe such as pointed out by Beecher. The last segment in the anaprotaspis is regarded as a telson, and consequently he finds the occipital segment to have been added later in front of the telson.

In several papers Raw (1927, 1937, p. 579) has discussed the cephalic segmentation in trilobites. Like Henriksen he finds the glabella originally to include six segments as demonstrated in several Meraspid larvæ and certain adul forms. Raw claims that the furrows suggesting the segmentation of the inter-ocular cheeks in the protaspis of the Olenellidae are not segmentary limits, but represent pleural furrows similar to those in the thorax and pygidium, furrows which he regards as having relation to muscles.

Richter (1932) follows Warburg and Henriksen in assuming a reduction of the second antenna, but he is inclined to refer the eye-ridges and at least a part of the palpebral lobe as belonging to this A_2 segment. The anterior part of the frontal lobe belongs to the A_1 segment.

In an earlier paper (1930, p. 92) I have discussed the relation between glabellar furrows and cephalic appendages. The larval development in the Trinucleidae shows that the glabellar furrows, serving as apodemes to muscles, appear at a later larval stage and therefore not necessarily mark the primary borders between succeeding segments. Instead of signifying six glabellar segments, the five glabellar furrows or pits in the adult indicate five pairs of appendages. This view was supported by Schulze (1936, p. 194), who regards the trilobites as having only one pair of antennæ and being related to the Merostomata such as has been emphasized by Ivanov (1933) and the present author (Størmer 1933, 1939).

Ivanov (1933) points out the primitive nature of the five limb-bearing segments in the trilobite head. The early ontogenetic stages of *Limulus* indicate the presence of four primary cephalic segments in this form which has the antennæ completely reduced. The number therefore corresponds to the number of the postoral segments of the trilobite head.

Recently Öpik (1937) discusses the cephalic segmentation and bases his conception on the supposition that the trilobites possessed six pairs of "crustacean" appendages. At the same time he points out in accordance with my studies, that each glabellar segment includes both the lobe and the furrow in front of it. Following Walcott, Swinnerton, Warburg, and Henriksen he regards the eye-ridges and palpebral lobes as belonging to the fifth segment reckoned from behind. Like Richter he assumes that the anterior portion of the frontal lobe in the glabella of the Olenellidae belongs to a special segment, the antennule segment. Öpik differs from other writers on trilobites in claiming the possibility of six instead of five glabellar furrows. This is based on the indication of a double second furrow in *Cybele*, a structure which seems to be of minor importance since irregular glabellar furrows are common among various trilobite groups.

Like most recent students of trilobites, Öpik claims the reduction of the second antennæ (A_2), but he presents a new explanation of this in presuming that the lateral eye was formed by the elaboration of the nerves belonging to the reduced antennæ (A_2). This assumption would necessitate the belonging of the lateral eye to a postoral segment, a condition quite different from that in other arthropods, where the lateral eye belongs to the preantennular or ocular segment innerved from a protocerebrum.

In a recent paper on the "Evolution of the Annelida, Onychpora, and Arthropoda" Snodgrass (1938) also deals with the segmentation of the trilobite head. He points out in accordance with Ivanov and Schulze the primitivness of the five larval, limb-bearing segments (antennæ and four pairs of legs) in the cephalon, but he does not separate any further segments in the acron carrying the eyes and the antennæ.

It appears from this brief review that the conceptions of the cephalic segmentation in trilobites are chiefly based on the number of segments expressed in the glabella of Meraspid stages and certain adult forms. The knowledge of the cephalic appendages has also been recognized, but the conclusions have apparently been too much influenced by the current opinion of a crustacean nature of the trilobites. The presence of six glabellar lobes in certain forms has led to the assumption that the cephalon originally possessed six pairs of appendages, although only five pairs are known in the appendage-bearing species. Concerning the interpretation of the frontal portion of the glabella, the opinions deviate considerably. It remains to be given a satisfactory explanation of the segmentation of this part of the glabella, an explanation which agrees with the structures of the early protaspis and with the present knowledge of the ventral appendages of the cephalon.

Present Interpretations of the Segmentation in the Protaspis and in the Cephalon of the adult Trilobite.

Studying the segmentation in fossil arthropods one has to bear in mind that the conclusions have to be based on the external shell only. Nothing of the internal structures except muscular markings on the inside of the shell is left in the fossil.

The numerous somites building up the arthropod body might form unites, tagmata, in which the somites are of a uniform character, or might be coalesced into one shield. The somites of the anterior portion of the body are always combined in one head-shield or head. The number of somites included in the head is, however, subject to considerable variation within the different arthropod groups. Before we discuss the cephalic structures in trilobites, it might be useful to consider briefly the general features in the segmentation of recent arthropodes. The views presented in the sequel are chiefly based on publications by Snodgrass (1935, 1938).

The cephalisation in recent arthropodes. In the polychaete annelids the primitive head or prostomium comprises the part of the trunk not invaded by the blastopore, i. e. the portion of the trunk anterior to the mouth. The prostomium has two pairs of appendages, the tentacles and the palpi (often also a median tentacle) and bears the eyes and the nuchal organ. The mouth is situated between the prostomium and the first segment of the body. The prostomium is innerved from a suprastomodeal nerve-mass or brain. The somites posterior to the prostomium are innerved from the ventral nerve cord.

In the arthropodes the head is always a more complex structure. The large cephalic lobes of the arthropod embryo probably correspond to the prostomium of the annelids. In certain primitive crustaceans the head is composed of the preoral portion and only one postoral somite. This primitive arthropod head which is called the procephalon, bears the labrum, the eyes, the first antennæ or antennules (A_1) and the second antennæ or antennæ (A_2), the latter belonging to the postoral somite. In other crustaceans the head includes 3—5 more somites with the following appendages: the mandibles, the first and second maxillæ, and the first and second maxillipeds. The cephalon of the Trilobita has evidently four postoral somites and the prosoma of the Merostomata six-seven postoral somites.

The postoral segments of the head might be easily distinguished at least in the early ontogenetic stages. A possible segmentation of the preoral portion, on the other hand, is more difficult to trace. It has been assumed by most zoologists that the preoral portion of the head primarily consisted of separate somites which had been incorporated when the mouth migrated backwards on the ventral side. As a chief support to this conception might be mentioned the occurrence of coelomic sacs in the mesoderm of this region. The coelomic sacs correspond to the first antennæ (A_1) and in some cases certain extra sacs, corresponding to a pair of transitory preantennal appendages and the labrum, might be distinguished. Traces of rudimentary preantennal appendages have been described in the embryo of a centipede and insect, but their actual presence cannot be said to have been established.

The development of the brain gives little information on the segmentation of the preoral portion of the head. In the procephalon the brain is generally divided into three parts: the protocerebrum, the deutocerebrum, and the tritocerebrum. The first innervates the eyes, the second the first antennæ (A_1) and the third the second antennæ (A_2). The tritocerebrum is derived from the first postoral somite. Nerves from the tritocerebrum innervate, however, the preoral labrum, and this, according to Snodgrass (1935, p. 481), "has led some entomologists to conclude either that the labrum belongs to the tritocerebral head somite or that the roots of the labral nerve have their origin in the protocephalon. Neither alternatives seems to be supported by facts". Concerning the trilobites, Henriksen (1926, p. 1—2) states that the hypostoma is homologous with the labrum which, since it is innervated from the tritocerebrum, commonly is considered as belonging to the antennal (A_2) segment. Snodgrass remarks that also the distribution of cephalic nerves to more posterior parts of the body indicates that the nerves are not restricted to their primary somites.

Several recent authors are not inclined to regard the preoral portion of the head as being formed by the combination of different primary somites. Holmgren (1916) and Hanström (1928) assumes that the division of the preoral portion of the brain into a protocerebrum and deutocerebrum is a secondary differentiation from an undivided archicerebrum. Sollaud (1923, 1933) points out that the first antenna appears as a uniramous appendage in contrast to the biramous second antenna and this, as well as the lack of an external segmentation of the preoral portion of the head, indicates that the A_1-somite hardly should be regarded as a separate, primarily postoral somite. Snodgrass (1938, p. 92) agrees with this conception, and claims that coelomic sacs might be formed for physiological purposes only and might therefore not have been developed by metamerism. Like the other authors mentioned, he regards the somite of the second antennæ (A_2=cheliceræ), innerved from the tritocerebrum, as the first true somite.

The present problem on a possible segmentation of the preoral portion of the head in arthropods might to a certain extent be elucidated by the studies of the early trilobite larvæ, which apparently show more primitive features than any of the living forms. Naturally only external traces of a segmentation might be expected in the fossil.

Before we discuss the segmentation of the protaspis it has to be mentioned that recent embryological research on the origin of the separate segments in the Annelida and Arthropoda seems to indicate that there are two different types of somites. From ontogenetic studies on polychaetes and *Limulus*, Ivanov (1928, 1933) arrived at the conclusion that in the early larva metamerism first appears as a subdivision of the body into a small number of somites. These somites, which appear more or less simultaneously, form the primary somites or larval segments. New segments are subsequently added to the primary somites by teloblastic growth in a subterminal generative zone (text-fig. 12 T). These new somites are called the secondary somites. Ivanov points out that among the polychaetes the different groups might have a different number of postoral primary somites. He finds that among the Arthropoda the Trilobita and Xiphosura have four postoral somites, while the Crustacea apparently have only two (only two postoral pairs of appendages in the nauplius). Ivanov draws the conclusion that the different arthropod classes are derived independently from various annelid groups with the same number of primary somites. Schulze (1936) and Snodgrass (1938) are of the same opinion, and the former has introduced the term larvatum to signify the unite formed by the primary segments. It is to be understood that the larvatum in general is not identical with the head of the adult. The head of the Trilobita corresponds to the larvatum, but in the Merostomata two or three more segments are added. Among the Crustacea some branchiopodes have a head corresponding to the few primary somites, but in most groups several secondary somites are incorporated in the head.

Returning now to the general arthropod somite, this is best studied in the postcephalic portion of the body where a fusion of segments have not taken place, or at least is less complex than in the cephalic region. Of interest in the present connection is the development of muscles and their apodemes on the inside of the shell.

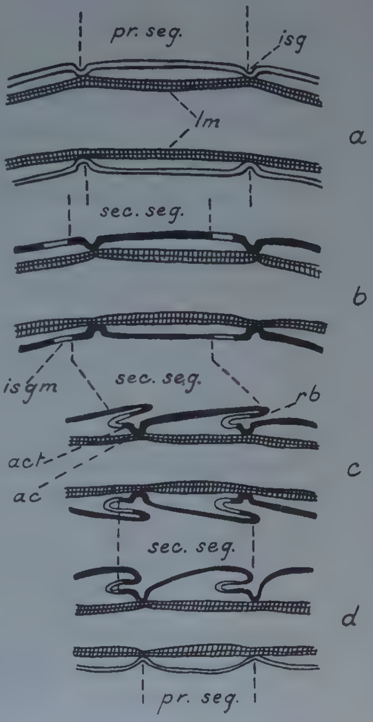


Fig. 11. Primary and secondary segments in the arthropod body. *a*=external shell not chitinized. *b*—*c*=Chitinisation (black) causes a secondary segmentation of the body. *d*=body-segments of trilobite. (*a*—*c* after Snodgrass 1935.) *ac*= anticosta or internal ridge forming the inside of the articulating furrow, *act*=acrotergite or articulating half ring, *isgm*=intersegmental membrane, *lm*=longitudinal muscles, *pr. seg.*=primary segment, *rb*=reflexed border, *sec. seg.*= secondary segment.

Text-fig. 11 a illustrates primitive somites of the type found in the body of polychaetes and in the abdomen of insect larvæ. Each somite is bordered by a transverse furrow or intersegmental groove *(isg)* which on the inside serves as an attachment of the longitudinal muscles. In arthropodes with a chitinous shell the borders of the separate movable segment do not necessarily correspond to the borders of the primary segment (*pr. seg.*) bordered by the intersegmental grooves (not to be confused with the primary somite defined above).

Text-fig. 11 b illustrates the common secondary segmentation by which some part of the somite in front is incorporated, and appears as an acrotergite or articulating half-ring in the trilobite terminology. By means of the soft intersegmental membrane *(isgm)* succeeding secondary segments are telescopically inserted into each other (c). In trilobites (d) the dorsal shell is divided in this way while the ventral integument apparently is thinner and softer resembling the type found in the worms. A very complex secondary division of the body segments is found in the thorax of insects, and in a later chapter a secondary division and fusion of thoracic segments in trilobites are discussed.

The separation of succeeding primary segments has externally to be based on the transverse furrow marking the attachment of the longitudinal muscles. In the previous part of the present work (1939, p. 172) I have tried to reconstruct the course of some of the major muscles of the trilobite body. The dorso-ventral muscles leading to the appendages were apparently attached to the inside of the shell below the articulating furrow (intersegmental groove) and the area just behind it. In several forms such as *Ceraurus*, powerful apodemes, "appendifers" project from a point just beyond the articulating furrow with which they communicate. The apodemes are very similar to the glabellar furrows which apparently belong to the cephalic appendages. Since they must be regarded as homologous structures, the glabellar furrows probably are situated in the anterior portion of the corresponding somite. The glabellar furrows, however, do not necessarily mark the anterior border of the somites. The ontogeny of *Reedolithus carinatus* (Angelin) has shown that the glabellar furrows might appear at a comparatively late larval stage, and thus mark the muscular apodemes rather than the primary division lines of succeeding somites (Størmer 1930, p. 95). Concerning the transverse furrows of the glabella in the early larvæ, however, these lines although absent in the earliest protaspis, apparently in the main features distinguish the division lines of the united segments.

The segmentation of the anaprotaspis and the trilobite cephalon. The segmentation is expressed in the axis and in several cases also in the pleural region. As pointed out in the previous chapter, the protaspides of the different trilobites agree in the major characters of the dorsal shell.

The axis appears very early in the ontogeny, but the transverse furrows are absent or very faintly developed in the earliest stages. As soon as the glabellar furrows appear they divide the axis or glabella into five lobes. The four transverse furrows are mutually alike and equally spaced. Since they appear so early in the dorsal shell, the furrows evidently mark the borders of succeeding segments and thus form the intersegmental grooves. The grooves divide the axis into five separate lobes. We have to consider whether the frontal and occipital lobes are of the same type as the remaining three which are bordered on both sides by glabellar furrows.

The frontal lobe is somewhat differently developed in the various genera. In the earliest stages of *Blainia* (?) (pl. 1, figs. 13, 14), and *Olenus* (text-fig. 9 a) the frontal lobe is not separated from the preglabellar field or preantennal segment. In later Protaspid stages, however, the frontal lobe becomes more vaulted than the preglabellar field from which it therefore might be separated. The same seems to be the case in certain Olenellidae such es *Elliptocephala* (text-fig.

5 b). Here, however, the confluence might not have been so significant as indicated in later illustrations.

In other forms such as in the primitive (though not very early) larva of *Holmia* (?) (text-fig. 4) the frontal lobe abuts clearly to the preglabellar field, and has the same dimensions as the following lobes. The same is indicated in the bilobed frontal lobe of *Paradoxides* (text-fig. 7 a). In the very early anaprotaspis of *Paedeumias* (text-fig. 5 a) the glabella is well bordered in front although the glabellar furrows are not yet developed.

The structure of these forms strongly suggests that the frontal lobe of the axis primarily comprises the axial portion of one segment such as the following lobes.

During later larval stages the frontal lobe of the glabella undergoes important changes. Already in the last anaprotaspis stage of *Blackwelderia* (pl. 1, fig. 12) the expanded frontal lobe has a pair of pits according to the somewhat schematic drawing of Endo. In *Olenus* I have had the opportunity to study the development of the lateral pits of the frontal lobe. The pits appear in the second Metaprotaspid stage and become more and more distinct until they form distinct glabellar furrows in the Meraspid stages as shown in Strand's figures. In *Paradoxides* the lateral pits appear for the first time in the Meraspid Period. The pits become very distinct and unite across the glabella, and are thus quite similar to the four primary transverse glabellar furrows (text-fig. 7 e). In adult stage the anterior furrows are maintained in certain species e. g. *P. insularis* Westergård, and *P. sjøgreni* Linnarsson (Westergård 1936, pl. 8, fig. 9; pl. 9, fig. 8). Similar conditions are found in the Olenellidae where the furrows are found in the adults of several species such as *Elliptocephala asaphoides* Walcott (1890 pl. 89, 90), *Callavia brøggeri* Walcott (1910 pl. 27, fig. 1) and *C. callavei* (Lapworth) (Raw 1936 fig. 1, p. 252). In *C. bicensis* Walcott (1910 pl. 41, figs. 9, 9 a) and in one drawing of *C. callavei* by Walcott (l. c. pl. 42, fig. 2) even six pairs of glabellar furrows are indicated, but the extra pair seems only to represent the anterior border of the eye lobes which are connected with the glabella. An extra pair is also claimed by Öpik (1937 p. 124, pl. 7 fig. 3) to occur in certain species of *Cybele*, but the extra furrow appears only as a part of a bifurcated second glabellar furrow, and hardly represents the apodeme of a special appendage.

The first glabellar furrows or antennuary pits are situated in the axial furrows almost at the antelateral corners of the glabella. Also in *Trinucleus* (Størmer 1930, text-fig. 39) the antennuary pits are situated far in front leaving little space to an extra segment in the frontal lobe of the glabella.

The pits of the frontal lobe have been differently interpreted by various writers. As mentioned in the historical introduction, Beecher (1895, p. 179) claimed that the six glabellar lobes did not indicate an additional pair of limbs, but are due to a division of the frontal lobe either by the greater or lesser extent of the eye-line across the axis, or by the marked development of muscular fulcra (apodemes).

The major part of more recent writers have, however, regarded the anterior pits as bordering an extra frontal segment in the glabella. Warburg, Henriksen, Richter, Raw, and Öpik have followed Kingsley (1897) in claiming a reduction of the antennæ (A_2) in most trilobites. The frontal lobe is expected to include both the A_1 and A_2 segments, the latter, in which the antenna is supposed to be reduced, is represented laterally by the eye-ridges and the palpebral lobes.

As pointed out above this view is apparently influenced by the assumption of a crustacean nature of the trilobite. It finds its support in the presence of six glabellar lobes in several trilobites. The hypothesis meets, however, with considerable difficulties:

1. Our present knowledge of a great number of protaspides shows that primarily the glabella includes five lobes, the frontal pairs of furrows indicating a sixth lobe appears but later in the ontogenetic development. 2. In several species in which the ventral appendages are known only one pair of antennæ occurs, and the antenna is uniramous and preoral and apparently represents the antennule. In *Cryptolithus* the five cephalic appendages correspond to the five pairs of glabellar furrows or pits, and since, from an analogy in the thorax, the apodemes occur in the anterior portion of each segment, the antennules belong to the fifth segment reckoned from behind. A reduction of one pair of appendages would therefore have taken place in front of the antennules and could therefore not have been the antennæ (A_2).

In explaining the anterior pits and the lobe in front of it, it seems natural to consider two possibilities. Either the two frontal lobes are homologous with the frontal lobe in the anaprotaspis, or the original frontal lobe has incorporated some part of the preglabellar field during the growth.

The anterior or antennuary pits evidently form the apodemes of muscles leading to the uniramous antennæ as indicated in *Trinucleus* and *Cryptolithus* (Størmer 1930, text-fig. 39). As mentioned above the apodemes are situated in the anterior portion of the corresponding somite. It might have been possible that the apodemes of the frontal lobe have migrated backwards as far as to the middle of the somite, which thus would comprise the complete frontal lobe.

The other explanation seems, however, more probable. A strong development of the frontal lobe of the glabella is a common feature in many trilobite forms. This is especially significant in certain "hydrocephalic" species of *Paradoxides* (text-figs. 7 g, h). In *P. pinus* (text-figs. 7 a—e) it is possible to study the development of the frontal lobe in relation to the eye-ridges on either side of it. In the late metaprotaspis (c) the lobe reaches further forward than in the anaprotaspis (a), a feature showing that the frontal lobe is expanding forwards during the larval development. In *Olenus* and *Elliptocephala*, where the frontal lobe is not bordered anteriorly in the earliest anaprotaspis, the forward expansion across primary segmentary borders might have been easily realized.

The strong development of the frontal lobe is apparently dependent on the more powerful development of the alimentary canal, which probably extended forwards from the mouth in a fold below the glabella just as in *Limulus*. As pointed out by Raymond, (1920, p. 81) it seems likely that larger stomachs were required when the larvæ changed their habits from a pelagic to an omnivorous more benthonic mode of life.

It seems therefore probable that during the larval development some part of the preglabellar field or preantennal segment was gradually incorporated in the frontal lobe. From comprising a single somite in the early protaspis, the frontal lobe in later stages apparently also includes a larger or smaller portion of the somite in front. In the reconstructions of the cephalic segmentation (text-figs. 2, 15, 16) some part of the preantennal segment is therefore tentatively indicated in the frontal portion of the glabella.

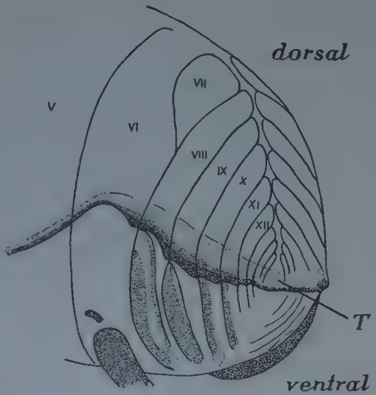
The occipital segment of the glabella is very similar to the segments in front. In the anaprotaspis the last segment, the fifth lobe of the glabella, corresponds in its position to the axis of the occipital segment. Several authors such as Henriksen (1926 p. 4) have, however, interpreted the last segment of the anaprotaspis as a telson in front of which new segments were successively formed. The occipital segment was thus formed at a later stage and was incorporated in the cephalon after the frontal segments had become united. This view is chiefly based on the fact that the occipital segment, especially the pleural portion of it, closely resembles the succeeding thoracic segments.

The present studies do not support the assumption mentioned. As pointed out in the following chapter, the pleural portion of the occipital segment must be regarded as a partly secondary formation caused by the transverse joint crossing the primary, oblique pleuræ. There seems therefore to be little reason for regarding the occipital segment as being later incorporated in the cephalon. In the early Protaspid stages of *Olenus* (text-fig. 9) the five glabellar lobes with their respective pleuræ are mutually so much alike that the last one can hardly be interpreted as a telson with the generative zone of growth in front of it on the dorsal side. Also the strong bending of the dorsal shell during the Metaprotaspid stages (text-fig. 10) seems to indicate that the formative zone had a ventral position.

In recent arthropodes the anus and the generative zone of growth have a ventral and subterminal position in the earliest stages of development. This might be seen in e. g. the nauplius of Copepoda and in the embryo of *Limulus*. In his detailed description of the ontogeny of *Limulus moluccanus* (Linnaeus) (=*Tachypleus gigas* Müller) Ivanov (1933) has clearly demonstrated the formation of new segments. He shows that primarily four somites besides the preoral portion of the head are formed simultaneously in the larva. These segments form the primary cephalon or larvatum. During further development new segments or somites are successively added to the larvatum. The new segments are not differentiated in front of a telson such as indicated in larval stages of crustacea, but are formed, one by one round a telepore at a subterminal point on the ventral side (text-fig. 12). The so-called telson in *Limulus* is not a real telson, in the sense of being situated beyond the segment-forming zone, but represents the fused tergal portions of several rudimentary segments in front of the telopore. The telson might therefore be compared, as indicated by Ivanov, with the dorsal spine in posterior segments of certain primitive trilobites such as *Olenellus* (=*Mesonacis*).

It seems therefore probable that the new (secondary) segments in the trilobite larva were formed in front of a

Fig. 12. Embryo of *Limulus*. Postlateral view showing the formation of secondary somites round a posterior telopore (T). (After Ivanov 1933.)



subterminal and ventral telopore such as in *Limulus*. The last segment in the axis of the anaprotaspis is consequently interpreted as belonging to the primary somites rather than forming a telson.

It might also be mentioned that Öpik (1937 p. 127 footnote) suggests the presence of a double occipital ring in *Holmia*, and claims that the ontogeny (Kiær 1916 p. 66—67) presents sufficient evidence for this view. Öpik apparently bases his conclusion on a more schematic drawing by Kiær (l. c. fig. 11 e), but in the adult specimens figured in the plates the occipital segment in the axis is not much broader than the segments in front, and therefore hardly is composed of two segments. As shown in text-fig. 14 a transverse line divides the occipital segment of the glabella into two parts; but if they should be regarded as belonging to different segments the same must have been the case with the thoracic segments having the same transverse line (*trl*) leading to the median spine. It seems far more likely that the transverse line only is part of the sculpture within one somite and does not distinguish separate segments.

Our knowledge of the early larval development of the glabella in trilobites makes it very probable that the glabella primarily is composed of five similar primary somites. During the larval development some part of the preglabellar field might probably become vaulted and united with the anterior glabellar segment forming an expanded frontal lobe.

The pleural areas of the cephalon in several cases also demonstrate the segmentation. As shown in pl. 1 this is shown in early larvæ of the Olenellidae and in the genera *Olenopsis* and *Olenus*, and to some extent in the posterior cephalic segments of *Paradoxides*.

A young larva of *Holmia* (?) (text-fig. 4) gives the best indication of the segmentation. The glabellar furrows continue laterally into pleural furrows directed outwards and slightly backwards. The pleural furrows are less distinct in the lateral parts, but the pleuræ corresponding to the five glabellar lobes are easily distinguished. As shown in the schematic drawing in text-fig. 2 and 13 the pleura of the first and second lobe is more extended than the second, third, and sixth. The pleuræ and the lobes between them are more or less concentrically arranged with the longest pleuræ projecting backwards. Most significant is the segment including the eye lobes and the frontal lobe of the glabella. As mentioned above this segment evidently bears the uniramous antennæ (A_1) and thus forms the posterior preoral somite. The segment might naturally be called the antennal segment. The four dosterior segments of the cephalon carry the biramous appendages and might consequently be termed the first to fourth leg segments.

In the early larvæ also of other Olenellidae the antennal segment is surrounded by a flat rim bearing the genal spines and the lateral eyes along the border towards the antennal segment. In relation to the flat or slightly concave rim the antennal segment forms an elevated roll inside it.

As mentioned in the historical introduction the rim outside the lateral eyes (the free cheeks) and the portion in front of the glabella have by most authors been interpreted as belonging to the ocular segment. Several zoologists have, however, claimed that the preoral portion of the head is not primarily segmented, and one of their arguments is the lack of an external segmentation in the recent arthropod embryos.

The primitive protoparian larva has a distinct segmentation of the dorsal shield, and the following features speak in favour of regarding the preoral portion as composed of several segments. 1. The roll here described as the antennal segment corresponds in width (longitudinal) closely to the typical postoral somites or leg segments. 2. The antennal segment is separated from the surrounding rim by the steeper anterior border of the roll. 3. The rim projects into short spines which originally were coalesced with the distal portions of the antennal and preoccipital pleuræ.

Although a flat rim might possibly develop from a preoral cephalic lobe, the mentioned characters seem to suggest that the preoral portion of the trilobite cephalon is composed of more than one segment. Since the rim or preglabellar field possibly forms a segment in front of the anntenal segment, I would prefer to call it the preantennal segment.

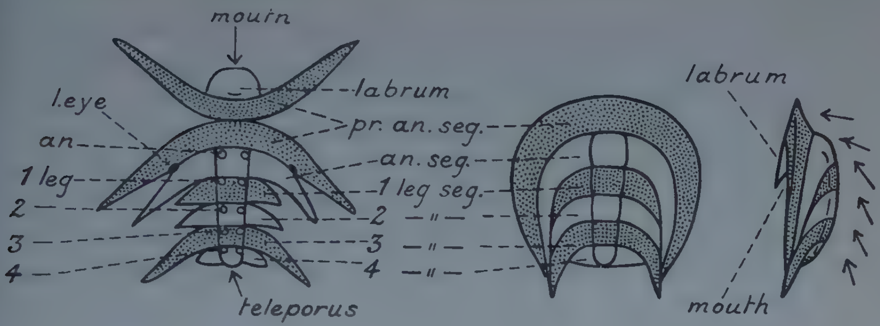


Fig. 13. Probable segmentation of the anaprotaspis *a* = somites with the pleural portions isolated. *b* = generalized type of primitive protoparian anaprotaspis. *c* = lateral view. *an* = area of attachment of muscles leading to the antenna. *an. seg.* = antennal segment. *l. eye* = lateral eye. *pr. an. seg.* = preantennal segment.

The term ocular segment might prove less useful because the visual organs might possibly alter their position in relation to their respective somites. As pointed out below, the preantennal portion of the cephalon might include several different elements, and it seems therefore possible to call this portion the preantennal segment complex. The term acron has been used for different portions of the head, and is therefore less applicable.

The preantennal segment is very little developed on the dorsal surface of the protaspis of the opisthoparian and proparian trilobites. In later stages and in the adult the preantennal segment is, however, well exposed on the dorsal surface. The preantennal segment has a reflexed border forming the rostrum, which is separated from the dorsal shell by the marginal suture. Kiær (1916) assumed that the rostrum formed a special segment, but later authors (Warburg, Henriksen) have found this less probable. In accordance with the views presented below on the significance of cephalic sutures, I find it less probable that the rostrum represents a special segment.

The hypostoma is separated from the reflexed border or doublure by a hypostomal suture, which might be absent in certain forms. The hypostomal structures in trilobites are only known in late larval or adult individuals, and the origin of the plate in front and below the mouth therefore remains unknown. It seems natural to homologize the hypostoma with the labrum of other arthropodes as emphasized by several writers. The labrum forms the first element in the sagittal plane through the cephalon. Since it is innerved from the tritocerebrum, i. e. from the gangliæ of the first postoral somite, Henriksen (1926), however, finds it not probable that the hypostoma belongs to the foremost portion of the head. Snodgrass (1935) on the other hand has pointed out that this might be of minor importance since the nerves might lead to somites outside their own. At present our knowledge of the hypostomal maculæ, though described in detail by Lindstrøm (1901), is too scarce to judge a possible homology with the "ventral eyes" in *Limulus* as discussed by Hanstrøm (1926) and in the Eurypterida (Størmer 1934). The "median eye", or median tubercle of the glabella, is well developed in the Cryptolithidae (Størmer 1920). Recently Hanstrøm (1934) has made an interesting comparison between the "median eye" of the trilobites and the combined dorsal organ and four-celled sense-organ in primitive crustacea. This sence organ is innerved from the tritocerebrum and the "median tubercle" might therefore belong to the first leg-segment.

In the trilobite larva it seems very difficult to assume that the preoral hypostoma belongs to the postoral first leg-segment. If that is the case one would have to interpret the hypostoma as a modified sternite across which the mouth had migrated backwards (or the sternite moved forwards), an explanation which seems hardly possibly to maintain. A frontal position of the hypostoma is expressed in the general character of the anaprotaspis of the primitive protoparian trilobites. As indicated in text-fig. 13 the concentric arrangement of the segments is significant. In lateral view one gets the impression that the different somites with their axial and pleural portions, were turned over so that their longitudinal axis, from being horizontal, became more and more declined forwards until they attained a nearly vertical position as indicated by arrows in the drawing. The frontal segment was accordingly flattened out with the pleurae curved backwards. Of the six segments visible on the dorsal surface the two frontal ones are almost completely turned over while the rest have an axis but slightly declined. This explains how the distal points of the preantennal, antennal and preoccipital pleuræ unite in the earliest stages.

The structures observed might support the earlier theory by Bernard (1894) on the ventro-posterior migration of the mouth by which the anterior cephalic segments turned over and to some extent attained a ventral position in front of the mouth. The problem cannot be elucidated by paleontological evidence alone, but the structure in the primitive trilobite larvæ might give evidence concerning the external segmentation of the dorsal side of the arthropod head.

The present studies seem to indicate the following segmentation of the adult cephalon in the Trilobita.

I. Preoral elements.

0. The preantennal segment complex (acron, ocular segment) comprising the hypostoma (?), the marginal doublure with the rostrum, the preglabellar field, the extraocular cheeks with the genal spines and secondarily probably the anterior portion of the frontal lobe of the glabella. The complex including the lateral eyes and the hypostomal maculæ (?) is probably innerved from a procephalon or part of an archicephalon.

1. The antennal segment (palpebral segment) comprising the primary first or frontal lobe of the glabella, the eye-ridges with a portion of the interocular cheek behind it, the palpebral lobes and a narrow, wedge-shaped portion behind them. The somite carries the uniramous antennæ (A_1) which probably are innerved from a deutocerebrum (or part of an archicephalon).

II. Postoral Elements.

2. The first leg-segment comprising the second glabellar lobe with the pleuræ on the interocular cheeks. The somite, including possibly a dorsal organ with a four-celled sense organ, carries the first pair of biramous appendages which evidently are innerved from the tritocerebrum.

3. The second leg-segment comprising the third glabellar lobe with the pleuræ on the interocular cheek. The somite carries the second pair of biramous appendages.

4. The third leg-segment or preoccipital segment comprising the fourth glabellar lobe with the pleuræ projecting into the intergenal spines. The somite carries the third pair of biramous appendages.

5. The fourth leg-segment or occipital segment comprising the fifth glabellar furrow or neck-ring with the pleuræ of which theposterior part forms the antelateral portions of the pleuræ of the first thoracic segment.

The present results strongly indicate that the trilobite cephalon includes four postoral somites such as emphasized by previous authors.

As mentioned above, Ivanov, Schulze and Snodgrass assume that these four segments belong to the primary larval somites (p. 112). Ivanov points out that the four primary, postoral somites in the trilobites correspond to the same number of primary somites in the Xiphosura, a feature which might indicate a more intimate relationship between the two arthropod groups. Our present knowledge on the earliest trilobite larvæ makes it very probable that the four postoral segments (as well as those in front of them) appear more or less simultaneously, while the following segments do not appear until the Metaprotaspid Period. The studies on the trilobite ontogeny thus present valuable support to Ivanov's view according to which the trilobite cephalon is composed of primary somites, while the thorax and pygidium is formed by secondary somites (except the antelateral portions of the pleuræ of the first thoracic segment, as shown in the following chapter).

The segmentation of the adult trilobite is indicated in text-figs. 14, 15 og 17. The new conception of the segmentation of the thoracic segments is based on the studies of the transverse suture separating the transitory pygidium from the cephalon, and is therefore dealt with in the following chapter.

The Development of the Joint between the Cephalon and the Transitory Pygidium, and the Segmentation of the Thorax and the Pygidium.

All previous writers have regarded the suture between the cephalon and the protopygidium, and in later stages between the thoracic segments, as primary division-lines between successive segments of the body. During my studies on trilobites I have gradually arrived at another conception concerning the segmentation of the thorax and pygidium, a view slightly touched upon in my previous paper (1939, p. 169).

In studying the segmentation of the thorax and pygidium one has to bear in mind that characteristic of the trilobites is the extensive lateral expansion of the body. The lateral lobes with their ventral doublures are thin tergal outgrowths from the lateral margin of the axis. The essential part of the trilobite body is restricted to the narrow axial portion bordered by the dorsal furrows.

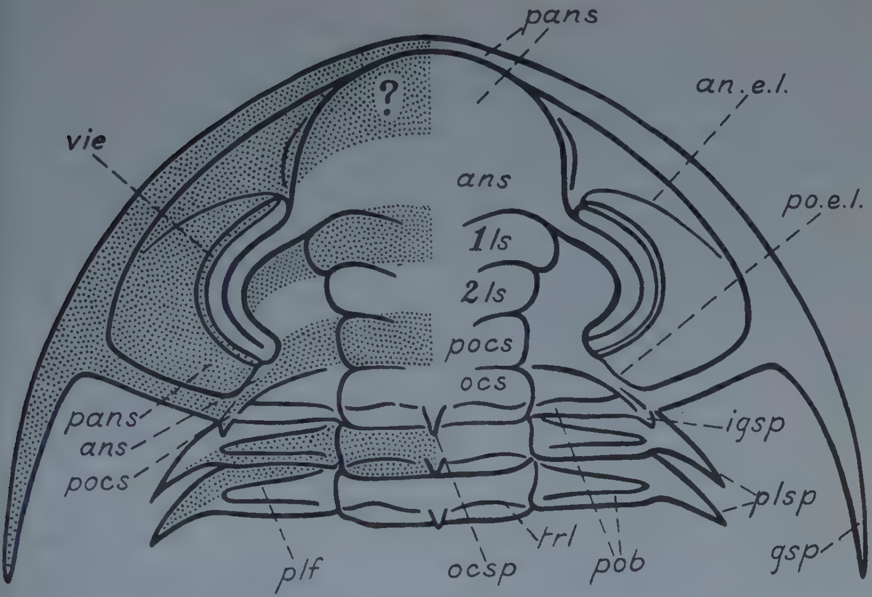


Fig. 14. The probable relation between the primary and secondary segmentation in the cephalon and two thoracic segments of *Holmia kjerulfi* (Linnarsson). Every second of the primary segments is shaded. (Cephalon based on specimen pl. 2 fig. 3.) *an. e. l*=anterior eye line, *ans*=antennal segment, *arhr*=articulating half ring, *gsp*=genal spine, *igsp*=intergenal spine, *ls*=leg segment (1—2), *ocs*=occipital segment, *ocsp*=occipital spine or tubercle, *pal*=palpebral lobe, *pans*=preantennal segment, *plf*=pleural furrow, *plsp*=pleural spine, *pob*=posterior border, *pocs*=preoccipital segment, *po. e. l*=posterior eye line, *trl*=transverse line of axial segments, *vie*=visual surface of lateral eye.

In the trilobite literature it has often been pointed out that the occipital segment, comprising the occipital ring and the posterior border of the cephalon, bears a considerable resemblance to the thoracic segments. The general resemblance has lead to the common assumption that the occipital segment was incorporated in the cephalon at a later phylogenetic stage just as the maxilliped segment in the head of certain groups of Crustacea.

Several recent authors (Swinnerton, Schulze) on the other hand have pointed out that the thoracic characters of the occipital segment are merely secondary formations, and do not give evidence of a later incorporation in the cephalon.

The occipital segment is well demonstrated in the larval stages of *Paradoxides* (text-figs. 7 e, 15 c). Compared with the thoracic segments, the posterior border forming the pleural portion of the occipital segment corresponds largely to the posterior pleural band of the thoracic segment. The furrow in front of the posterior border, the lateral continuation of the occipital furrow, corresponds to the pleural furrow of the thoracic pleura. The anterior pleural band of the thoracic segment would then be expected to find its counterpart in the posterior portion of the cheek or pleural area of the cephalon. The anterior portion of the pleura of the occipital segment is thus not marked off from the rest of the pleural portion of the adult cephalon.

In *Holmia* (text-fig. 14) the pleural furrow of the occipital segment is broad especially near the axial furrows. In the occipital segment a similar broad furrow is visible in front of the posterior borde (*pob*). In *Holmia* the intergenal rib (the continuation of the intergenal spine *igsp*) forms, however, an antelateral border, which therefore might be compared with the anterior pleural band of the thoracic segment.

Turning now to the early ontogenetic stages of *Holmia* or similar genera of the Olenellida (text-fig. 5), it becomes apparent that the intergenal rib forms the lateral portion of the preoccipital segment.

The oblique furrow behind it is interpreted as the division-line between the pleura of the preoccipital and occipital pleura. In the adult stage the oblique furrow runs from the occipital furrow in a postlateral direction towards the posterior margin. The posterior margin, forming the transverse joint between the cephalon and the first thoracic segment, thus forms a distinct angle to the direction of the oblique furrow appearing as a segmentary division-line in the protaspis. Since the furrow apparently is homologous with the pleural furrow of the thoracic segments, we must assume that also in the separate thoracic segments the transverse anterior and posterior borders of the pleuræ form an angle to the primary segments.

In his last paper on the Olenellidae Raw (1937, p. 580) evidently is aware of the homology between the interocular oblique furrows in the Protaspid cephalon and the pleural furrows of the thorax and pygidium. Following the current views on the segmentation of the trilobite body, he is forced to postulate that the interocular furrows in the larval cephalon, just like the pleural furrows, are merely adaptions in close relation to the muscles. This leads to the impossible conclusion that the interocular furrows of the early larva in primitive trilobites have nothing to do with the intersegmental division-lines, i. e. with the original segmentation.

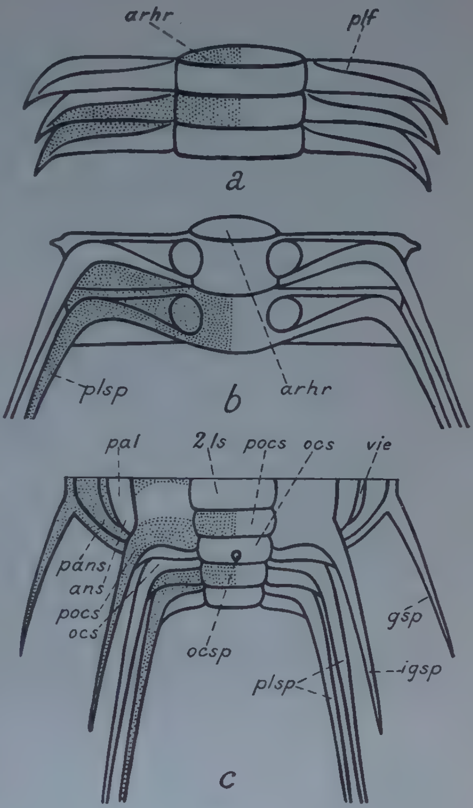


Fig. 15. Primary and secondary segmentation in different trilobites. Every second of the primary segments is shaded. *a*=two thoracic segments of *Paradoxides*. *b*=the same of *Acidaspis buchi* Barrande (after Barrande). *c*= posterior portion of cephalon and two thoracic segments of Meraspid stage of *Paradoxides*. Letters the same as in text-fig. 14.

In order to elucidate the connection between the primary segmentation and the transverse joints in the trilobites, we shall now consider the ontogenetic development of the transverse suture appearing at the close of the Protaspid Period.

The early protopygidium is little known in the Olenellidae. A first metaprotaspis of *Elliptocephala* has been figured (text-fig. 5 d), but of the slightly older stages only one fairly incomplete drawing by Ford is at hand (text-fig. 3). The pleural furrows of the protopygidium are directed outwards and backwards, and correspond to the direction of the primary segments in the cephalic portion of earlier stages. In early Meraspid stages (pl. 1, fig. 4) the transverse posterior border of the cephalon thus forms a distinct angle to the direction of the pleural furrows of the protopygidium.

Recent studies by Westergård on *Paradoxides* larvæ (text-figs. 7 a—e) are of considerable interest in the present connection. As stated above (p. 75) the larval development strongly suggests that the intergenal spine belongs to the preoccipital segment just as in the Olenellidae. The following spine, which is of distinctly the same type, forms the pleural extension of the occipital segment. In a late metaprotaspis (7 b) the present pleura, which has an oblique direction, seems to be crossed by a transverse furrow, which later in the first Meraspid Stage develops into an open suture or hinge-line between cephalon and the transitory pygidium. A reconstruction of the structure is attempted in text-fig. 17 c and pl. 1, fig. 7. The postlateral portion of the occipital pleura thus becomes a part of the first "segment" of the transitory pygidium, while the antemedian portion remains in the cephalon.

In *Paradoxides* we thus find considerable evidence for the assumption that the joint or hinge-line between the cephalon and the transitory pygidium represents a secondary transverse suture crossing the primary segmentation.

Among other trilobite groups distinct pleural furrows are seen in the interocular cheeks of the protaspis of *Olenopsis* and *Olenus*. The present studies of *Olenus* have demonstrated in the main features the development of the transverse hinge-line. The evolution is indicated in the semidiagramatic drawing in text-fig. 10. The intergenal spines apparently form the postlateral projections of the preoccipital segment just as in the mentioned trilobite genera. A characteristic feature is the strong convexity of the early Metaprotaspid stages. On the convex interocular cheeks the pleural furrows are directed outwards and backwards in a curve. The postcephalic segments have an almost vertical position. They are bent down chiefly along a transverse line between the bases of the intergenal spines. Through the Metaprotaspid stages one observes how the line becomes more and more distinct and in the last stage a posterior marginal rim is formed along it. Along this posterior border the transverse suture between the cephalon and the transitory pygidium appears at the entrance of the Meraspid Period.

The structures observed seem to demonstrate that the transverse suture crosses the primary segmentation and therefore does not conform with the segmentary divisions. The conditions in *Olenus* thus agree with those in the Olenellidae and in *Paradoxides*. Particularly in *Olenus* the formation of the transverse suture might be explained as due to technical reasons. The convex surface of the protaspis, as well as the oblique direction of the segmentary borders, did not furnish amlpe conditions for the formation of a functioning hinge-line between two separate solid shields.

A conception of a secondary line of division between the cephalon and the transitory pygidium involves considerable consequences as to the segmentation of the thorax and pygidium in the adult. It means that all the thoracic pleuræ of primitive multisegmented trilobites

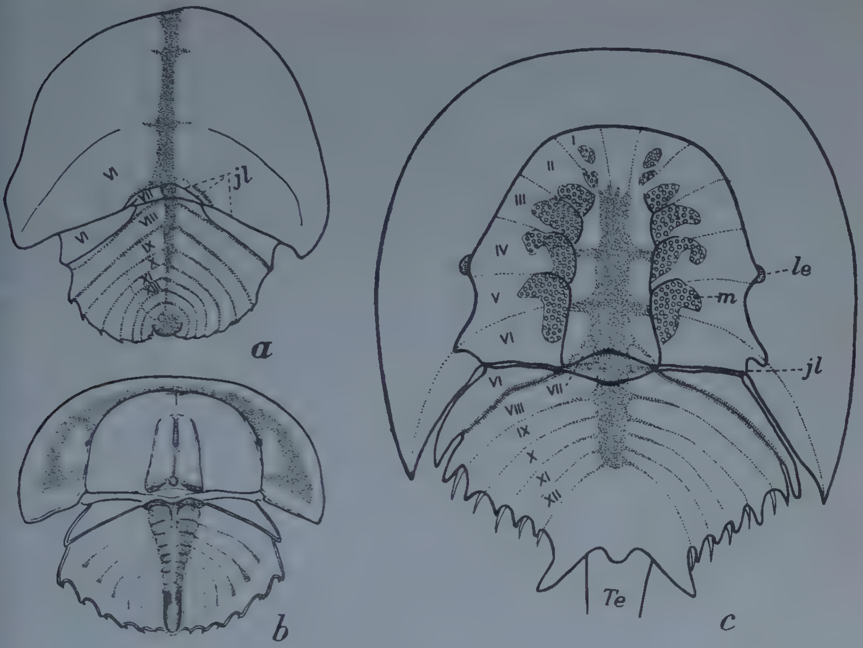


Fig. 16. Primary and secondary segmentation in *Limulus*. *a*=embryo, *b*="trilobite" stage, *c*=adult. I—XII=primary segments, *jl*=jointline between prosoma and opisthosoma, *le*=lateral eye, *Te*=telson. (Slightly modified after Ivanov.)

such as the Olenellidae and Paradoxidae were secondary formations developing partly by fusion and partly by secondary division of succeeding primary pleuræ.

At first sight this seems to be a highly specialized feature in the otherwise very primitive trilobites. It is, however, to be remembered that all the postcephalic segments, originally formed at the subterminal point, migrate forward through a coalesced protopygidium or transitory pygidium (shown by Stubblefield in *Shumardia*), and only secondarily become free thoracic segments. A number of segments remain fused in the true pygidium at the close of the Meraspid Period.

Among recent Arthropoda intrasegmental division of the body into movable parts is known in the Xiphosura and in many insects (Snodgrass 1938, p. 114). Also in the common arthropod tergite a secondary segmentation takes place as shown in text-fig. 11. A valuable support to the present conception of the secondary segmentation of the trilobite body is found in the structure of the joint or hinge-line between prosoma and opisthosoma in *Limulus*. Thanks to the detailed ontogenetic studies by Ivanov (1933) it has been possible to demonstrate how the transverse joint-line crosses the primary segmentation. The primary segmentation is similar to that in trilobites. On the larger pleural area the segments are directed outwards and backwards as might be seen in text-fig. 16. In the larva the seventh limb-bearing segment (the pregenital or chilaria-segment) is seen to be considerably reduced. Only the median portion of the somite is visible on the dorsal surface (text-figs. 15a, c). In the early stages the embryo is strongly vaulted, and later it becomes more flattened out such as is characteristic of the earliest free larva. During this development the distribution of the yolk apparently influences the further development of prosoma and abdomen. The prosomal yolk developing into the hepatic cæca reaches back to a transverse line crossing the sixth somite (text-fig. 16 a). At this line the dorsal and ventral integument lie close to each other, and here the transverse joint-line between prosoma and opisthosoma gradually develops. (Ivanov 1933, p. 282.) In the axial portion the joint-line, which has a certain extension in longitudinal direction, does not deviate so much from the segmentary division line, but in the pleural area the transverse hinge-line crosses the oblique primary pleura just as in the trilobites.

In *Limulus*, which in many ways has proved to be related to the trilobites, we thus find structures confirming the views presented above.

The mentioned facts make it probable that in trilobites the transverse joints between the pleuræ of the thoracic segments, or between these and the cephalon or pygidium, are secondary formations crossing the primary segments. Each thoracic pleura probably contains portions of two succeeding segments coalesced along the pleural furrows.

In the thoracic segments and in the pygidium the articulating half-ring of the axis apparently belongs to the segment in front, according to the secondary segmentation found in recent arthropodes (text-fig. 11).

The present view of a secondary segmentation of the dorsal shell in trilobites is expressed in text-figs. 14, 15, 17. This conception gives a natural explanation of the much disputed occipital segment and intergenal spine in trilobites. It also explains in a satisfactory way the interocular furrows in the earliest larval stages, and the occurrence of characteristic pleural furrows not only in the thoracic pleuræ but also in large pygidiæ (i. g. Asaphidae and Phacopidae), where no particular development of muscular apodemes seems to be necessary within each segment. In flat forms the strong ribs of the pygidium might serve as supporting structures forming "corrugated plate" as demonstrated by Richter (1923), but the strong pleural furrows also occur in strongly vaulted pygidiæ such as in *Chasmops*.

It might be objected that transverse furrows, corresponding in position to the transverse sutures, are present already in the transitory pygidium. This seems, however, to be of little importance since one might expect to find the lay-outs of the suture before the thoracic segments are detached. Concerning small and larger pygidiæ, it seems therefore logical to regard forms with large pygidiæ not as forms in which a greater number of the posterior segments have become fused, but to regard them as types in which the releasing of free thoracic segments has become delayed and not fulfilled.

Among the numerous types of trilobites the thoracic segments show considerable difference. Barrande (1852) tried to divide the trilobites into two different groups based on the structure of the thoracic segments. According to the morphology of the pleuræ the trilobites were placed in two groups: 1. "plèvre à sillon" and 2. "plèvre à bourrelet". As mentioned by Warburg and others the latter group is to be regarded as derived from the former. Among the many different types of pleuræ figured by Barrande (l. c. pl. 4—6) the type represented by *Paradoxides* (text-fig. 15 a) and many other genera seems to be the most primitive and most common type. Such forms as *Ceraurus* (included in group 1.) have, in spite of the elaboration of the test, an oblique pleural furrow indicating the same composition of two half segments.

In certain forms such as *Lichas* the pleural spine seems to be formed by both segments, since the pleural furrow extends into the spine itself. Also in the spineless pleura of *Sao* both segments seem to form the distal portion.

The detachment of the thoracic segments, previously coalesced in the transitory pygidium, might have taken place somewhat differently within different trilobite groups. Especially in the more aberrant genus *Acidaspis* (Barrande l. c. pl. 1, figs. 15, 16; pl. 37, fig. 25) the course of the spine deviates considerably from that in other trilobites. The primary segments seem to have been directed outwards and slightly forwards before they turn backwards at the pleural spine. Text-fig. 15 b illustrates the possible connection between primary and secondary segments.

In the family Olenellidæ several genera have the third thoracic segment strongly developed. According to my present interpretation of the joints, the powerful pleural spine belongs to the second thoracic segment, i. e. the sixth leg-bearing segment. It is of interest to notice that in *Limulus* the same sixth segment is strongly developed and forms the "intergenal angle" in the prosoma. (Ivanov also includes the genal angles of the prosoma in the sixth segment, but I agree with Snodgrass (1938, p. 112) that the acron or preantennal segment embraces the other segments just as in trilobites.) The strong development of the pleural portion of the second thoracic segment in primitive trilobites might possibly suggest a connection with the prosoma of the Chelicerata.

In this connection might be mentioned that the so-called Panderian organs, forming excretory (?) openings in the lateral doublure of the pleuræ (Siegfried 1936), are situated below the pleural furrow, and thus apparently have a more or less intersegmental position according to the present interpretation of the segments. The anterior pairs of openings occur in the cephalon, probably between the preoccipital and occipital segment.

The Development of the Cephalic Suture and their phylogenetic and systematic Significance.

The present investigation and conception of the cephalic segmentation in trilobites might throw new light on the much disputed problem on the origin and nature of the cephalic sutures. The partly "mechanic principles" suggested in the formation of the transverse hinge-line or suture might be applied also in explaining the development of the cephalic sutures during the larval period.

Primarily we shall briefly mention the various sutures and the different opinions concerning their origin. The problem is dealt with in a great number of papers, but in this place I shall only refer to the recent articles by Richter (1932 a) and Stubblefield (1936), the latter having critically quoted the various opinions in a special paper on the cephalic sutures.

Concerning the function of the sutures their importance to the ecdysis is generally assumed, while their use in facilitating the movements of the dorsal shell seems less convincing.

In classification the sutures have been of primary importance. The sutures have been the only single character in the trilobite morphology which have proved useful in establishing a general system of classification. The Salter-Beecher system is generally adopted in spite of considerable criticism and modification. Of Beecher's three Orders: Hypoparia, Proparia and Opisthoparia, the former has been rejected by most writers chiefly on the grounds that it included degenerate forms of the two remaining orders, and therefore cannot be regarded as ancestors of these. Swinnerton erected the Order Protoparia to include forms with a primary absence of facial sutures, but, since his group includes very different, even non-trilobite forms, it has not been adopted by recent writers. Neither has the separation of the Olenellidae into a special Order (Poulsen) met with much approval. At present the great number of trilobite genera are placed in the two Orders Proparia and Opisthoparia, and of these the former comprises only a small number of genera compared with the latter. But even this broad systematic division has its weak points. Hence the Family *Calymenidae*, with its suture crossing the genal angle, has been referred both to the one and the other of the mentioned Orders. Quite recently Kobayashi (1936) has described a genus *Jujuyaspis*, which in spite of proparian sutures evidently belongs to the Family Olenidae of the Opisthoparia. The primary taxonomic value of the facial sutures has been doubted by several recent authors, and the systematic division has more and more been based on a combination of morphological characters, by which a number of genera have been united in separate Families or Suborders (Kobayashi 1935).

Concerning the phylogenetic value of the facial sutures, it has been demonstrated that opisthoparian genera have passed through a proparian larval stage, and therefore might have had proparian ancestors. It has also been hinted that the facial sutures might have had something to do with the primary segmentation.

The different cephalic sutures are briefly mentioned in the following. The hypostoma is attached to the doublure by a transverse hypostomal suture, which, however, is lacking in the Olenellidae and several other Cambrian genera. A marginal suture separating the dorsal shell from the doublure is found in several trilobite groups such as Olenellidae, Harpidae and Cryptolithidae. In the Olenellidae the suture is to a great extent ventromarginal, crossing the genal angles below the spines, not above, such as in the Cryptolithidae. The ventromarginal suture in the Olenellidae has been called the perrostral suture by Richter (1932 b, p. 139), because it remains uncertain whether it represents a rostral (Kiær, Warburg, Raw) or marginal (Swinnerton) suture.

The doublure in front of the hypostoma is pierced by two longitudinal sutures, the connective sutures, which might be confluent, forming a median suture. The portion of the doublure between the connective sutures and in the hypostomal suture might be bordered in front by a transverse rostral suture, which thus separates a special plate which is called the rostrum. From the anterior corners of the rostrum the facial sutures run backwards on the dorsal surface of the cephalon. The sutures pass along the inside (median side) of the visual surface of the eye, and cross the lateral or posterior margin either anterior to the spine (Proparia) or posterior to it (Opisthoparia).

Different interpretations have been given of these sutures. The classical conception of Barrande (1852) claims that the facial sutures were united in front through the transverse rostral suture, thus forming "la grande suture" homologous with the marginal suture. The connective and hypostomal sutures were regarded as independent structures (the suture of the Olenellidae was unknown).

From the studies on the ventromarginal suture and large rostrum in the Olenellidae, Kiær (1916) and Warburg (1925) arrived at another explanation. They claim that the ventral suture, formed by the connective and rostral suture, was the primary suture separating the rostral segment or sclerite from the rest of the cephalon. At the same time the facial suture of the Olenellidae was regarded as being obliterated.

Among the more recent writers, Henriksen (1926) and Richter (1932 a) regard the connective sutures as direct continuations of the facial sutures. Richter supposes that these combined sutures might either unite in front forming a median suture (which might become fused and obliterated), or in connection with a secondary rostral suture border the rostrum which is thus interpreted as a secondary formation instead of a primary as claimed by Kiær and Warburg.

Only Beecher (1897) has paid serious attention to the larval development when judging the nature of the cephalic sutures. At his time, however, the early trilobite larvæ were little known in detail, and up to the present an early protaspis of one species has often been compared with a late protaspis of another.

It was the merit of Beecher to point out the migration, during the earliest larval stages, of the lateral eyes from the margin towards their more median position in the adult. Simultaneously with the appearance of the eye, the facial suture and the free cheek outside it developed and travelled over the margin. Since the eyes first appear at the margin, Beecher made the hypothetical conclusion that the free cheeks had a ventral position in the early stages, and in the earliest larvæ even the lateral eyes were supposed to have had a ventral position. Following Bernard, who assumed that the crustacean head was formed by the bending under of the anterior segments in an annelid, Beecher was inclined to interpret the free cheeks as a preantennal (ocular) segment, which in the primitive larvæ had a ventral position in accordance with the views of Bernard (Beecher 1897, p. 110). In "higher" trilobites the eyes were supposed to attain their intermarginal position more rapidly during the early ontogeny. Accordingly Beecher regarded the trilobites with a typical marginal suture *(Harpes, Trinuclens* and others) as being the most primitive types on account of their presumed ventral free cheeks (Hypoparia). According to this conception the Olenellidae with their intermarginal eye lobes in the anaprotaspis, would be the most advanced trilobites.

The conclusions of Beecher have met with criticism. The possession of ventral eyes in the larvæ is purely hypothetical, and Stubblefield (1936, p. 417) points out the inconsistency in argument when Beecher postulates that the suture borders the ocular segment or free cheecks, while at the same time the functional visual spots of *Harpes* are situated well within the marginal suture. Beecher claims the Cambrian trilobite larvæ to have ventral and marginal eyes; he omits the Lower Cambrian Olenellidae. In this old and primitive group the rudimentary lateral eyes of the protaspis have a distinct intermarginal position not much different from the position in the adult. When Beecher claims that the eyes have a less marginal position in the "higher" trilobites, he apparently means the larvæ of the Devonian *Acidaspis* and *Corydocephalus* (pl. 1, figs. 39, 40), but these eye-structures seem little convincing. In *Calymene* and *Dalmanitina* the eyes are marginal even in late protaspis stages. It is also to be mentioned, as pointed out by Warburg (1925, p. 29), that in the case of the Cambrian larvæ of *Sao* and *Ptychoparia* Beecher erroneously traced the facial suture to the posterior margin, and thus interpreted the probable intergenal spine as the genal spine.

In considering the cephalic sutures, Warburg (1925), Raw (1925) and especially Stubblefield (1936) have paid attention to the ontogeny as regards the primitiveness of the proparian contra the opisthoparian head-plan of the trilobites. The presence of proparian sutures in the larva of the opisthoparian genus *Peltura* (Poulsen 1923) was interpreted as suggesting that the proparian type was ancestral to the opisthoparian. Stubblefield looks upon the adult proparian trilobites as permanently neotenous opisthoparians.

Concerning the Olenellidae, apparently all writers except Raw regard this group as having an opisthoparian headplan. Most authors, such as Ford, Walcott (early papers), Beecher, Moberg, Kiær and Warburg, interpret the presumed traces of a facial suture to result from a secondary fusion of a normal opisthoparian suture. A number of other writers, however, such as Walcott (later papers), Swinnerton, Poulsen and Stubblefield, look upon the structures as sutures "in being". Raw's theory of a revolving backwards of a procranidial spine is discussed and criticised above (p. 65).

We shall now consider the evidence in favour of an opisthoparian head-plan in the Olenellidae.

Primarily the general structures of the cephalon of the Olenellidae bear a striking resemblance to Cambrian opisthoparians such as *Redlichia* and *Paradoxides.* Particularly the glabella, the eyes, the expanded cheeks with the genal spines, the doublure with the hypostoma, the thorax and pygidium are much alike. It might, therefore, seem natural to homologize the structures, and to claim the presence of a rudimentary or obliterated suture with the same course as the true facial suture in the typical opisthoparian trilobites.

In fact certain structures might appear to confirm the presence of an incomplete suture. Moberg (1899) pointed out the presence in *Kjerulfia* of a faint raised line, which in its position corresponds to the course of the posterior branch of the facial suture. The discovery of Moberg was confirmed by Kiær (1916, p. 81) who found: "a fine raised line, that runs in an arc from the posterior edge of the eye to the posterior margin in front of the intergenal rib." And in addition to this line another sometimes occurs which Kiær describes as "running from the anterior edge of the eye to the marginal brim, in a markedly receding arc". While the former is interpreted as traces of the posterior branch of the facial suture, the latter with doubt is referred to the anterior branch, which in its course recalls the facial the suture in *Paradoxides rugulosus* Corda.

In order to study in detail these important structures, I have examined a large number of specimens of *Holmia kjerulfi* (Linnarsson) and *Kjerulfia lata* Kiær from the Lower Cambrian at Tømten in Norway. The best specimens are illustrated in pl. 2, figs. 1, 3—5. The posterior line, which might be called the posterior eye-line (*pl.*), is visible in many specimens, but not in all. The line appears on the internal mould as a faint raised line, as mentioned also by Raw (1936, p. 241). On the dorsal surface the ridge reaches the occipital furrow, but is not found to cross this segment as might be seen in the reproduced photographs. In a specimen showing the surface-sculpture and thus representing the upper surface of the test (pl. 2, fig. 4), the line forms only a boundary between the smooth cheek postlateral to the eye and the more reticulated surface of the interocular cheek.

In *Kjerulfia lata* Kiær (pl. 2, fig. 1) the line is also faintly visible, running in postlateral direction and becoming obliterated before it reaches the margin, which is not marked off by a posterior marginal furrow such as in *Holmia*. The line or ridge is not so distinct as shown in the reconstruction presented by Kiær (1916, text-fig. 12). In *Callavia* the line coalesces with the intergenal ridge (Raw 1936).

On account of its position it might seem reasonable to interpret the ridge as representing traces of the posterior branch of the facial suture, which has a similar course in opisthoparian trilobites. This explanation has, however, met with criticism. Both Lindström (1901, p. 15, 16) and Stubblefield (1936, p. 421) explained the ridge as a postocular remnant of the antennal segment or larval ridge in the sense of Warburg. Stubblefield points out that the locus of fused sutures is never represented by a raised line or ridge, but in the case of supposed vestigal cephalic sutures usually appears as a groove. Since the raised line apparently belongs to the internal mould, the last argument seems to be of little value, but it might be mentioned that in the Cryptolithidae certain raised lines on the internal mould run from the lateral eyes towards the genal angles, and these lines Raymond

(1920, text-fig. 25) presumes to be the genal cæca and not facial sutures as claimed by Ruedemann (1916). Concerning the posterior eye line in the Olenellidae Raymond (1917, p. 208) also considers a segmental origin of the line, and speaks of "a natural line of weakness, because it was the line of division between the original first and second segments of the dorsal side". This largely agrees with the present studies on the cephalic segmentation. As shown in text-fig. 14 the preantennal and antennal segments apparently abut against each other along the mentioned line, and near the margin the distal portion of the preoccipital segment touches the preantennal segment. The so-called posterior branch of a facial suture in the Olenellidae might therefore just as well represent the division-line between the distal pleuræ of the preantennal and antennal segment. The anterior border of the intergenal rib would then represent the division-line between the distal pleuræ of the antennal and preoccipital segment, and at the posterior border, between the preantennal and preoccipital segment. This interpretation offers an explanation also of the fact that the posterior eye-line, bordering the postlateral portion of the antennal segment, does not cross the hind border.

Concerning the "anterior branch of the facial suture" in the Olenellidae, it is much less significant than the posterior branch. The anterior eye-line *(al)* is visible as a faint line in a number of specimens of *Holmia* and in the figured specimen of *Kjerulfia* (pl. 2, figs. 1, 3, *al*). The line appears as a faint furrow running from the anterior point of the eye outwards and backwards in an arc as far as to the broad marginal rim. In the Swedish species *Kjerulfia lundgreni* (Moberg 1899) the line is described as a raised line, but in the specimens figured in the present paper it has more the character of a very faint furrow. There is little evidence in favour of interpreting the line as a remnant of a suture. Primarily the line does not extend to the margin. Secondarily a line of this type might be explained as due to preservation. A slight compression of the cheeks with the elevated lateral eyes might probably create a bending line in this place. The preservation might also to some extent cause an imprint of the posterior border of the rostrum. In this connection might be mentioned the supramarginal suture which Resser (1928) meant to find in the cephalon of *Olenellus* (=*Mesonacis) fremonti* Walcott. Although such a suture also seemed to be indicated in some of Walcott's figures of *Olenellus (=Paedeumias)* and *Wanneria*

(1910, pl. 34, fig. 3; pl. 30, fig. 20), it is probable that the observed supramarginal line is merely the imprint of the normal submarginal suture on the inner surface of the dorsal shell, as pointed out by Raw (1936).

From the mentioned reasons I find no direct evidence of the anterior and posterior eye-lines representing traces of a facial suture in the Olenellidae.

The marginal suture (or perrostral suture) has clearly been demonstrated in several different genera of the Olenellidae. As shown in text-fig. 18 the suture is submarginal except in the genal area where it runs inwards across the doublure. A specimen of *Olenellus (=Paedeumias)* described by Walcott (1910, pl. 34, fig. 6) illustrates as shown by Swinnerton the mechanism of the moulting. The rostrum (the greater part of it is not preserved) with the hypostoma is loosened along the marginal suture, and turned backwards round the postlateral corners of the cephalon. A marginal suture of this type is a common feature among the Arthropoda. It is found in the Branchiopoda, Xiphosura and Eurypterida as well as in many other animal groups.

In the young larva we do not know the course of the marginal suture, but it seems possible to draw certain conclusions as to its presence and position. As soon as the first ecdysis took place in the Protaspid Period the marginal suture was evidently developed, and during the numerous later growth stages it must have been present to facilitate the écdysis. Following the stages backwards it seems highly probable that the early protaspis with its subcircular outline had a simple marginal suture, which did not necessarily extend as far as to the hind margin. From analogy with *Limulus* (comp. text-fig. 25 in Størmer 1934) the marginal suture might reach only some distance beyond the broadest part of the cephalon as suggested in text-fig. 18 (Olenellidae larvæ). During the ontogeny the cephalon of the Olenellidae changes in outline from subcircular to semicircular by the further growth of the postlateral portion of the head. The genal spine develops in the late protaspis after the marginal suture was established. As pointed out above the preantennal segment is well developed on the dorsalside of the head in the earliest larvæ of the Olenellidae. During the further growth stages only the genal angles with the genal spines are subject to more extensive development. They develop and migrate from a medioposterior position out-

outwards where they form lateral outgrowths of the dorsal shell. It seems therefore probable that the ventral course of the hind portion of the marginal suture in the adult Olenellidae is due to a postlateral overgrowth of the dorsal shell during the larval development.

In the Paradoxidae and other typical opisthoparian trilobites the preantennal segment was only to a small extent developed on the dorsal side in the protaspis. The lateral or extraocular portion was not present, and the larva thus had not attained the broad and marginally flattened cephalon characteristic of the typical trilobite head. Evidently the larva, just as in the embryological stages of *Limulus* (Ivanov 1933) (comp. text-fig. 12), was more convex and the pleural portions were little developed or at least they had a ventrolateral position. The ontogeny has shown that the dorsal development of the preantennal segment chiefly began in the late Protaspid Period and was very significant in the early Meraspid Period.

It is natural to assume that also the earliest larva of the Paradoxidae possessed a suture to facilitate the ecdysis. Since no facial suture is visible across the dorsal surface the suture was either marginal or ventral. It seems most likely that the suture followed the broadest part of the head and hence was marginal, and in fact the position of the genal spine close to the palpebral lobe in the metaprotaspis of *Paradoxides* (text-fig. 7 b) indicates this. Being marginal the suture had to run along the palpebral lobe or rudimentary lateral eyes which were marginal in the protaspis of the Opisthoparia and Proparia. Since the pleural portion of the preantennal segment is not developed on the dorsal side in the protaspis, the marginal suture had to cross, more or less diagonally, the pleural portions of the preantennal segment. During further larval development the extraocular portion with the genal spine gradually appears outside the suture preliminarily marginal. Compared with the Olenellidae this portion is developed from the ventrolateral portion of the shield and therefore develops below instead of above the suture, i. e. by undergrowth instead of overgrowth of the shell. During the Meraspid Period the extraocular portion of the preglabellar field develops rapidly and increases in size. The preglabellar field shows a special rapid growth in antelateral direction. The different degree of development of the various parts greatly influences the course of the suture. From being marginal in the protaspis the suture becomes straightened out in the early Meraspid Period where the marginal suture thus has attained a dorsal, facial position, and in later stages the dorsal or facial suture becomes more or less S-shaped with a deep reentrant at the lateral eye. The ontogeny thus indicates that the marginal suture of the protaspis, during the larval development, is transformed into a facial suture.

To the present conception might be objected that one would expect the marginal suture to maintain its marginal position, i. e. to migrate outwards simultaneously with the development of the extra-ocular portion. This objection seems, however, to be of little value. During the ecdysis the elevated lateral eyes, with their nearly vertical visual surface, form a difficult point by the removal of the shell. During the larval development the suture probably becomes intimately connected with the lateral eye, and the suture maintains its position across the eye also after the eye has attained a distinctly intermarginal position. The migration of the suture towards the margin in forms with reduced lateral eyes (Richter) might be seen as confirming the present conception.

The structures of the Olenidae are similar to those described in the Paradoxidae, but the palpebral lobes are much shorter. Also in the Olenidae it seems natural to assume the presence of an early marginal suture crossing the primary preantennal segment. During the Meraspid Period the antelateral portion of the cephalon is first developed, hence the suture first appears on the dorsal surface at this place. As pointed out by several scientists the larva passes through a proparian stage of development. Gradually the suture migrates further backwards by the increase in size of the postlateral angles.

Concerning the Proparia the lateral eyes of the protaspis are situated along the anterior margin, and are less lateral than in the Opisthoparia. During the larval period the preantennal segment develops in front and outside the lateral eyes which thus become intermarginal. Simultaneously the probable marginal suture changes into a facial suture. In later stages the postlateral portion of the preantennal segment apparently remains little developed, so that the suture remains outside the genal angle with the intergenal spines.

In the Harpidae and Cryptolithidae the suture is marginal or supramarginal. In the former group the suture is marginal and follows the outline of the broad perforated brim. In the latter the suture is also marginal and follows the outline of the perforated brim, but at the genal angles the suture crosses the genal spine on the upper side as shown in text-fig. 17. Characteristic of both trilobite families is the perforation of the fringe by numerous hour-glass-shaped hollow pillars. All the pillars are intersected at their most narrow portion by a horizontal suture forming an internal continuation of the marginal suture (Richter 1916, Størmer 1930). The horizontal suture separates the ventral doublure from the dorsal shield.

Unfortunately we do not know the protaspis of the Harpidae or Cryptolithidae. In Degree 0 of the Meraspid Period the suture is marginal and therefore, as I have pointed out earlier (1930 p. 93), does not elucidate the problem of the relation between the marginal and facial suture. (I only mentioned that the supramarginal course of the postlateral portion of the suture might perhaps suggest that the suture was not marginal in the protaspis.)

With regard to the nature and origin of the marginal suture in the Harpidae and the Cryptolithidae, the following conceptions might be considered.

1. The facial suture is completely reduced and a secondary marginal suture is developed.
2. The facial suture has migrated to the margin and is thus converted into a marginal suture.
3. No facial suture was ever present, the marginal developed as a primary suture.

The first interpretation is especially advocated by Lake (1907), Swinnerton (1915), Reed (1916) and Richter (1915, 1921), and appears to be the current explanation by most paleontologists. Lake stressed the relationship between *Trinucleus* and the opisthoparian genus *Orometopus*, and assumed that the facial suture and lateral eyes had become reduced in the former. Reed (1916) is inclined to find remnants of a facial suture in a bending-line across the cheek in *Trinucleus*. Richter (l. c. p. 200) argues that when the eyes of *Harpes* are homologous with those of other trilobites the free cheeks are found on the upper side of the cephalon, and the facial suture therefore is to be expected at the place of the eyes. The marginal suture is consequently explained as a new formation.

To the mentioned arguments might be objected that the relationship between *Orometopus* and *Trinucleus* is purely hypothetical as stated also by previous authors. Concerning the oblique bending-line of the cheeks in *Trinucleus*, I have previously (Størmer 1930, p. 93) pointed out that the line probably bounds the reticulated posterior portion from the steep and smooth anterior portion. The line of argument offered by Richter is based on the assumption that the facial suture has a fixed position in relation to the cephalic segmentation, an assumption which is not based on facts. On the contrary, the migration of the facial suture together with the reduction of the eyes in the Phacopidae (see below) rather indicates their labile position in relation to the dorsal shield.

The second conception has been little considered. From their elaborate studies on Upper Devonian Phacopidae, Rud. and E. Richter (1926, p. 9, 184—190) were able to demonstrate the migration of the facial suture towards the margin with the reduction of the compound eye. The development is illustrated in series including the subgenus *Dianops* (Rud. and E. Richter l. c., Richter 1932 a and Stubblefield 1936). From this point of view it seems probable that the supramarginal suture in the Conocoryphidae also has originated from a lateral migration of a previous facial suture in secondarily blind forms (Warburg 1925, p. 45, 59, Raw 1925, p. 261 and Richter 1932b, p. 182). The slightly supramarginal course of the marginal suture in the earliest larva of *Tretaspis* gives no real indication of a lateral migration of a facial suture. In certain Cryptolithid genera such as *Reedolithus* (Størmer 1930) the lateral eyes apparently were functional, and in this case a migration of the suture seems very unlikely.

The third conception has been advocated by the Danish scientists Henriksen (1926, p. 29) and Poulsen (1927, p. 311). Poulsen assumes that the marginal suture is primary, that it is homologous with the marginal or perrosteral suture in the Olenellidae and that this suture existed before the facial suture in trilobite phylogeny. On the other hand he does not homologize the marginal and facial suture, and his assumption of the primitiveness of the marginal suture is apparently based on its presence in the primitive Olenellidae.

Following the views offered in the present paper, it is natural to explain the marginal suture and the lack of the facial suture in accordance with the third conception. This conception of a primary marginal suture finds a certain support in the larval development. As mentioned earlier, the first Meraspid larva has a very broad cephalon with distinctly intramarginal lateral eyes (pl. 1, fig. 41).

This suggest a larval development different from that in the Opisthoparia and Proparia, but approaching that of the Olenellidae, which also have the extraocular portion of the cephalon developed in the early larva. Concerning the facial suture, one would expect that if the Harpidae and Cryptolithidae, or their ancestors rather, had had a facial suture of the opisthoparian type, the facial suture also had a similar ontogenetic development, i. e. that the lateral eyes or palpebral lobes were marginal in the protaspis. This would mean that the broad extraocular portion with the powerful genal spine, present in the first Meraspid stage of *Tretaspis*, had developed very rapidly through a few moultings in the late Protaspid Period. With our present knowledge of trilobite ontogeny it therefore seems improbable that the Harpidae and Cryptolithidae, or their ancestors, had facial sutures which later became obliterated. The broad larval cephalon with its intermarginal eyes suggests that the marginal suture was primary and homologous with the marginal (perrostral) suture in the Olenellidae.

The views here presented lead to a new conception on the nature and origin of the cephalic sutures in trilobites.

The marginal suture was apparently present in the larva of all trilobites. In the Olenellidae and probably in the Harpidae-Cryptolithidae the preantennal segment is well developed on the dorsal side of the head-shield already in the Protaspid Period, and the marginal suture is parallel to the outline of this segment. In the Opisthoparia the larval suture is also marginal, but the preantennal segment develops on the dorsal side not before the Meraspid Period. The previously marginal suture therefore becomes intramarginal in the Meraspid Period, and, since the suture maintains its connection with the lateral eye (in order to facilitate the ecdysis of this protruding point), the suture is transformed into a facial suture. In the Proparia a similar development takes place, but here the dorsal development of the preantennal segment is even more arrested. The postlateral portions of the preantennal segments develops but slightly, and the suture accordingly maintains a position corresponding to a certain larval stage in the development of the Opisthoparia.

The present studies thus lead to the conclusion that the facial suture in the Trilobita is homologous with the primary marginal suture, and the different course of the cephalic sutures is dependent on a rapid

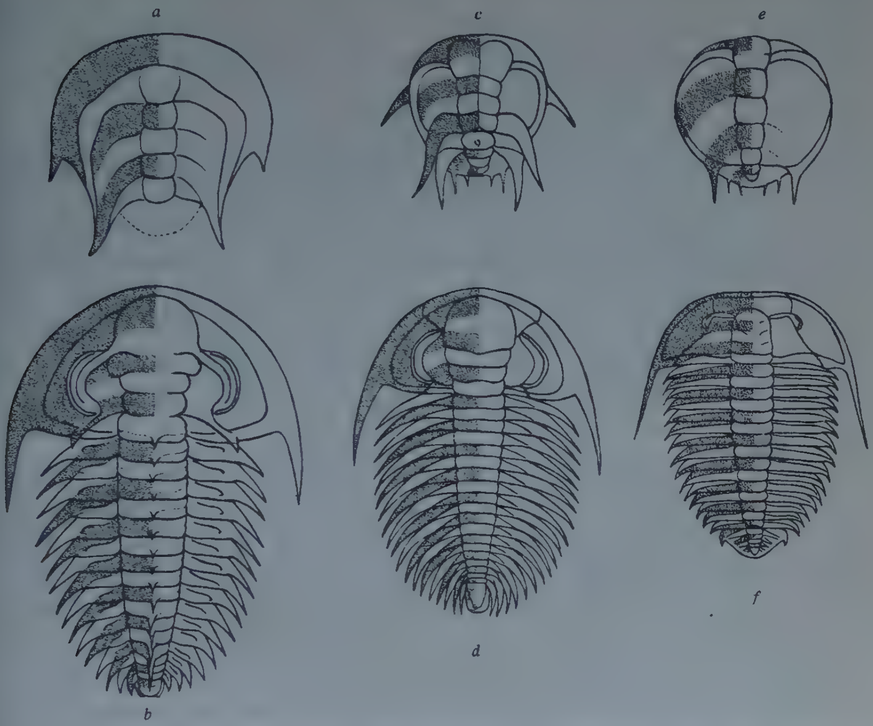


Fig. 17. Primary and secondary segmentation of protaspides and adult stages of trilobites from the Lower, Middle and Upper Cambrian. Every second of the primary segments is shaded. *a-b* = *Holmia kjerulfi* (Linnarsson) (the protaspis might possibly belong to *Kjerulfia lata* Kiær). *c-d* = *Paradoxides pinus* Holm MS (the protaspis, probably belonging to this species, is reconstructed after illustrations published by Westergård). *e-f* = *Olenus gibbosus* (Wahlenberg).

or arrested dorsal development of the preantennal segment in the larva.

The development of the different sutures is suggested in text-fig. 18.

The present interpretation has the advantage to previous views because it is based on the ontogenetic development, and at the same time satisfies the mechanical principles and agrees largely with the successive geological appearance of the different evolutionary stages.

The explanation to some extent corresponds with the views of Barrande according to which the facial, rostral and marginal sutures form part of a common "grande suture." Like Barrande I interpret the connective sutures as secondary formations, while the hypostomal suture possibly coincides with primary segmental limits. The connective sutures probably developed largely from mechanical reasons in order to permit the body to pass out of the slough during the ecdysis. On the other hand the occurrence and course of the connective suture do not, however, give a convincing support to an assumption of a merely mechanical origin of these sutures. The connective sutures show a variable development in the different trilobite groups, and in the Eurypterida similar sutures seem to be present simultaneously with a marginal suture (Størmer 1934, p. 17—28). This might perhaps indicate that the connective sutures not merely facilitate the ecdysis, but the elaboration of these structures might possibly have taken place at a later phylogenetic stage independent of the other sutures. Future studies might elucidate the origin and nature of the connective sutures.

Beecher's interpretation of the cephalic sutures was also based on the ontogeny, which, however, at that time was very limited. In contradiction to the present studies, he claimed that during their phylogenetic development the lateral eyes migrated "from the ventral side, first forward to the margin and then backwards over the cephalon to their adult position". In the larval development this means that the more advanced forms have the lateral eyes rapidly appearing on the dorsal surface, while in the primitive forms they remained on the ventral side. As Raymond (1917) points out, Beecher's system cannot explain the conditions in the Olenellidae where the eyes are dorsal in the earliest larval stage. The present conception is more or less opposite to that of Beecher. On account of the arrested development on the dorsal surface of the preantennal segment, the eyes, phylogenetically, approach the margin more and more in the first larval stages.

The views of Poulsen (1927, 1932) agree in several points with those set forth in the present paper. As mentioned above he argues that the marginal suture is phylogenetically older than the facial suture, and he therefore places the Olenellidae in a separate Order beside those proposed by Beecher. He does not, however, consider the marginal and facial suture as being homologous.

We shall now briefly consider the systematic value of the cephalic sutures. As mentioned above, diverging opinions have been expressed with regard to the importance of a trilobite classifictaion based on the course of the cephalic sutures. Recent workers especially, have strongly criticised Beecher's system of classification. His

Order Hypoparia is rejected by most writers, and even a division into the two Orders Proparia and Opisthoparia is discarded by certain scientists.

Swinnerton's Order Protoparia was established on theoretical grounds comprising "Trilobites and Trilobite-like organisms in which the absence of facial suture is primary". He includet in this group the little known *Nathorstia* (which has been interpreted as a fresh-moulted *Neolenus*) and *Marella*, which in spite of trilobitean appendages belongs to a separate group related to the trilobites.

As pointed out by several authors (Warburg, Raw and Richter), a group including non-trilobite forms is of little use to the trilobite classification. With the present interpretation, however, of the cephalic sutures in the trilobites, the Olenellidae fulfill the requirements of Swinnerton's Order Protoparia. It might therefore seem reasonable to maintain the Order Protoparia in a restricted sense, comprising only very primitive trilobites with a primary marginal suture. Since the Lower Cambrian Olenellidae, with their primary marginal suture and characteristic larval head-plan, apparently fulfill the requirements of such a group, it seems natural to establish a separate Trilobite order, the Protoparia, including the Olenellidae. The name Mesonacida suggested by Poulsen does not seem appropriate since the family name is changed into Olenellidae, and in addition to that, the more neutral name Protoparia might prove more useful if other families have to be included in the Order.

In spite of frequent criticism of the Order Hypoparia, it seems to me there are certain reasons for maintaining at least provisionally this order of Beecher. Unfortunately our knowledge of the larval development is too scarce to permit a more definite conclusion as to the presence of a special Order. As advocated above, the marginal suture of typical members of the group is probably homologous with the marginal suture of the Olenellidae, i. e. the members of the Protoparia. In this case the families of the Hypoparia must either be placed in the Order Protoparia or constitute a separate Order for which Beecher's name Hypoparia is naturally maintained. In fact Raymond (1917, p. 209) mentions this possibility although he would place the Hypoparia as the most primitive members of the Protoparia. The members of the Hypoparia seem to differ from the typical Protoparia in having a decided marginal, or, if a genal spine is present, a partly supramarginal, suture. The intergenal spines are absent already at the beginning of the Meraspid Period. They also differ in lacking distinct glabellar furrows in the early Meraspid stages. A special characteristic seems also to be the reduction or absence of lateral eyes, a feature which is unknown in the Protoparia.

For these reasons I am inclined provisionally to maintain the Order Hypoparia, and regard it as forming an early offshoot of the trilobite stem as suggested in text-fig. 18.

It remains also to be settled which families should be included in the Hypoparia. Besides the typical Cryptolithidae it seems natural to include the Harpidae, which have so many peculiar characters in common with the former group. The much larger number of thoracic segments seems to be of minor value since up to 17 segments have been counted in the pygidium of *Cryptolithus* (Størmer 1930, p. 41). Also the Raphiophoridae have many characters in common with the Cryptolithidae. The suture is supramarginal or intramarginal and generally regarded as a true facial suture. In spite of this I am inclined to follow Raymond (1917) in including the Raphiorphoridae in the Hypoparia. Poulsen (1932, p. 313) also placed the Conocoryphidae in the Hypoparia, but I agree with Stubblefield (1936, p. 416, p. 419) who, like several previous workers, places this group closer to the Ptychoparidae. The Eodiscidae probably belong to the Proparia on account of the sutures in *Pagetia* and the proparian—opisthoparian type of protaspis. The position of the Agnostidae is more doubtful. Their relationship to the Eodiscidae is not convincingly demonstrated. On the contrary the early larva shows little resemblance to young proparian trilobites and recalls more the larva of the Cryptolithidae. Provisionally I am inclined to include the Agnostida in the Hypoparia. The peculiar genus *Shumardia* was included by Richter (1932 a) in the suborder or superfamily Cryptolithidae. Other writers such as Broili (1924) and Stubblefield seem more inclined to place the genus in the Conocoryphidae. It is difficult to decide, but, since the early larval stages seem to deviate from the normal proparian-opisthoparian development, I might suggest with doubt referring the genus, with its apparently marginal suture, to the Hypoparia.

The Order Proparia comprises a small heterogenous group of minute Cambrian and larger Ordovician-Carboniferous forms. The ontogeny might suggest that the opisthoparian trilobites have developed from proparian ancestors, and Stubblefield (1936) gives the

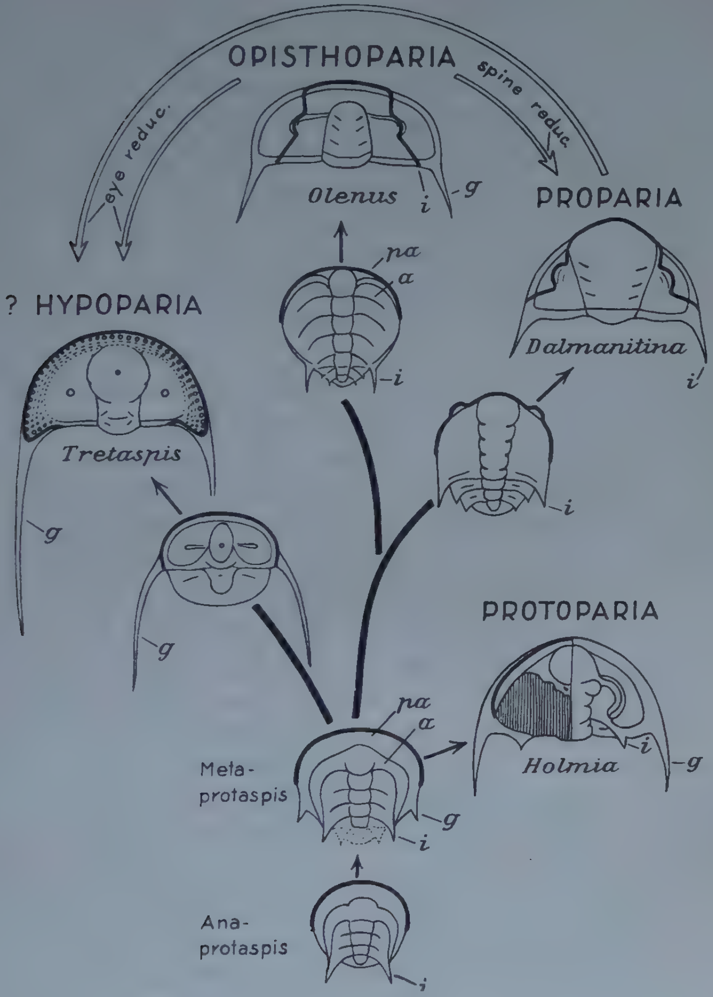


Fig. 18. A suggestion for a trilobite classification based on the development of the preantennal segment and the cephalic sutures. In the trilobites figured the solid black lines indicate the course of the marginal or facial sutures. The black arrows connect different growth stages of the same form. The strong black line indicates the probable relationship of the different trilobite orders. The white arrows suggest a secondary derivation of certain forms on account of a reduction of the lateral eyes or genal spines. *a*=antennal segment, *g*=genal spine, *i*=intergenal spine, *pa*=preantennal segment.

interesting suggestion that the small Cambrian members of the Proparia are to be considered as neotenous forms. As shown in the last chapter, however, the Proparia, in spite of their proparian larva, might be regarded as the most advanced trilobite order.

As pointed out by Warburg and others, the Phacopidae, including the Families Cheiruridae, Encrinuridae and Phacophidae, apparently have little to do with the Cambrian families. Also the Cambrian forms belong to families of remote relationship. In discussing the Proparia, Kobayashi (1935) points out that each group suggests a relationship to earlier opisthoparian trilobites, and he therefore deduces that the Proparia merely might represent the terminals of evolutionary lines. This gives an interesting support to the views set forth in the last chapter. Although the opisthoparian trilobites pass through a proparian stage of development, the general phylogenetic development suggests that the Proparia forms the most advanced group.

Richter (1932 a) includes in the Proparia the four superfamilies Eodiscidae, Norwoodiidae, Burlingidae and Phacopidae. In the Eodiscidae he also places the Agnostidae, but provisionally I prefer to separate this family as mentioned above. Besides these four groups several others have been considered in connection with the Proparia. In forms without lateral spines the systematic position is difficult to decide. The Calymenidae form a well-known case. The Family has been referred to both the Proparia and Opisthoparia, and has also been regarded as forming a link between the two orders. *Pharostoma*, however, appears to belong to the Opisthoparia and the typical Calymenidae are therefore generally referred to this group. In this connection it might, however, be remembered, as pointed out by Stubblefield (1936, p. 416), that true proparian families such as the Cheruridae might include opisthoparian genera.

With the absence of a genal spine it seems probable that a proparian suture might be secondarily attained among the Opisthoparia. Walcott (1916) describes and figures the Cambrian genera *Menomonia*, *Dresbachia* and *Millardia* which show proparian tendences in the development of the sutures, but yet seem to be true opisthoparians. Secondarily attained proparian characters are well demonstrated by Kobayashi (1936) in the genus *Jujuyaspis*. In spite of proparian sutures this early Ordovician form evidently belongs to the Olenidae, and belongs to the *Peltura-Acerocare* line of development in the uppermost Cambrian.

Also in genera with genal spine proparian sutures might be indicated. The Cambrian *Cedaria* (Walcott 1925) has a "typical" proparian cranidium, but the shape of the free cheek with its genal spine shows the opisthoparian nature of the genus.

In text-fig. 18 the development of a secondary proparian structure is indicated by a white arrow. Another arrow signifies a secondary development towards hypoparian structures such as demonstrated in Eodiscidae and Phacopidae.

The Order Opisthoparia includes all the remaining trilobite families and thus constitutes by far the largest Order. At just mentioned certain opisthoparians might attain proparian characters by the loss of the genal spine. On the other hand a secondary hypoparian structure might develop by the reduction of the lateral eyes just as in the *Proparia*. An opposite development might possibly have taken place in the Raphiophoridae. If they are typical hypoparians the marginal suture has migrated inwards in these convex forms, but it has no connection with a development of lateral eyes.

The present research indicates that a modified Salter-Beecher classification of trilobites has a natural foundation in the early larval development.

Each of the trilobite orders has apparently its specific larval development. The Protoparia is evidently the most ancestral group. The Hypoparia branched off from the main stem (possibly more than once) at an early phylogenetic stage. The proparian-opisthoparian line of development probably evolved from the Protoparia, or closely related forms in the Precambrian. This trend gave rise to different groups of Proparia and to the most potential trilobite order, the Opisthoparia. Text-fig. 18 illustrates in the main features the lines of development suggested above.

If we regard the arrested development of the dorsal portion of the preantennal segment as a major feature in the trilobite development, the Proparia might represent the main evolutionary trend and include the most advanced forms among its last members, the Phacopidae.

In the following is suggested a provisional classification of the Class Trilobita based chiefly on the ontogenetic development.

I. Order *Protoparia.*

Primitive trilobites with ventromarginal or marginal cephalic suture; lateral eyes well developed; preantennal segment well developed on dorsal side of protaspis; intergenal spines present in Anaprotaspid, Metaprotaspid, Meraspid and partly Holaspid Periods. Lower Cambrian. Superfamily Olenellidae (=Mesonacidae).

II. ? Order *Hypoparia.*

Trilobites with marginal, supramarginal or ventromarginal? suture; lateral eyes absent or little developed; protaspis broad with preantennal segment probably well developed on dorsal side; intergenal spines absent in Meraspid and later Periods.

Middle Cambrian?—Upper Devonian. Superfamilies: Cryptolithidae, Harpidae, Raphiophoridae?, Agnostidae?, Shumardidae?.

III. Order *Opisthoparia.*

Trilobites with facial suture crossing the margin behind genal angles, at the corners of which genal spines might occur; protaspis with preantennal segment slightly or not developed on dorsal side; intergenal spines present in the Metaprotaspid and Meraspid Periods. Lower Cambrian—Permian. All remaining superfamilies exclusive of the Proparia.

IV. Order *Proparia.*

Trilobites with facial suture crossing the margin in front of genal angles, at the corner of which intergenal spines might occur; protaspis with preantennal segment not developed on dorsal side, intergenal spines present in Metaprotaspid and later Periods.

Lower Cambrian—Lower Carboniferous. Superfamilies: Eodiscidae, Norwoodidae, Burlingidae, Phacopidae.

Evolutionary Principles indicated in the phylogenetic Development of the Trilobites.

The present conception of a probable phylogenetic classification of the trilobites might prove to be of some interest in elucidating certain general principles in organic evolution. In the following the present results are discussed in relation to the current views on arrested development, and the establishment of particular morphological characters.

A characteristic principle in organic evolution is the general retardation or hampering of the ontogenetic development known as neoteny. In neoteny the general development of the larva is arrested, so that the individual reaches sexual maturity without attaining the morphological characters expressed in adult specimens of other members of the group. As mentioned above Stubblefield (1936) has interpreted the small Cambrian proparian genera as being neotenous opisthogarians.

The present studies seem to indicate that, during the phylogenetic development of the Trilobita, one character, namely the dorsal development of the preantennal segment, is retarded or arrested at an increasing degree from the more primitive to the more advanced forms. One might speak of a "partial neoteny", indicating the retardation of one character in the morphological development. The arrested development of this single character has, according to the present conception, greatly influenced the entire development and radiation of the trilobite stock. The arrested development has caused the ramification of the trilobite class into four separate orders. The different orders are distinguished by the various development of the ecdysial sutures which, in spite of their largely mechanical origin, seem to express in the major features the general phylogenetic development.

The mentioned evolutionary principle indicated in the phylogenetic development of the Trilobita is apparently described by Schulze (1936, p. 195) in recent genera of the Acarina. Schulze demonstrates a partial retardation in the development of *Eriophyes*. He points out that since a general arrested development has not taken place, the development cannot be interpreted as a case of neoteny, and he introduces the name merostasis for this "Organ- oder Teilepistasis". The mentioned author emphasizes that this evolutionary principle plays en important part in the differentiation of species and genera in the animal kingdom, and the retardation might take place during the embryonic or postembryonic stage of development. Previous authors seem to have expressed similar views.

The phylogenetic development of the Trilobita seems therefore to a great extent to have been influenced by the evolutionary principle known as merostasis. Among the trilobites, however, the merostasis apparently has not only caused a differentiation into species and genera, but even into separate orders.

It is of interest to notice that the retardation in the dorsal development of the preantennal segment seems to have appeared rather suddenly in the phylogenetic development of the trilobites. In the Lower Cambrian the Pasific genus *Redlichia* bears considerable resemblance to the Olenellidae amongst other things in the structure of the posterior part of the body. *Redlichia* belongs, however, to the opisthoparians, and we might therefore assume that the retardation in the ontogenetic development appeared rather suddenly in the early Lower Cambrian or more probably in late Precambrian time.

We might consider the retardation or merostasis in the development of the preantennal segment as a new character of evolution appearing rather suddenly among the protoparian trilobites. By doing so we might compare the present case of merostasis with the evolution of new morphological characters in other animal trends. In this connection it seems fruitful to consider the studies of Schindewolf (1936) and others on the evolution of special morphological characters. This author discusses the appearance of new morphological types in various animal groups. Paleontological evidence indicates that the development of a new morphological character of a higher order first appears in the earliest ontogenetic stages, and is depressed in later stages by the dominant characters of the ancestral type.

This development is well demonstrated in certain graptolites (Bulman 1933, fig. 1) where the elaboration of the thecæ first appears in the proximal end of the rhabdosome. The same feature is well studied in other invertebrates where the ontogeny also is demonstrated "within the shell".

Schindewolf (1936) has described and figured several invertebrate series, three of which are shown in text-fig. 18 a-i. Only three phylogenetic stages are indicated in each of the series, comprising genera of Foraminifera and Cephalopoda (Nautiloidea and Ammonoidea).

In certain Foraminifera a new character represented by a double row of chambers (white) appears primarily only in the earlier ontogenetic stages. In presumably later phylogenetic stages the double row is found also in adult stages. Since the development apparently is not verified by occurrences in distinct succeeding strata, the present line of evolution is not quite certain, and some authors claimed an opposite direction of the development in order to satisfy the current recapitulation theory. Series of other invertebrate groups, however, seem to corroborate the conception presented by Schindewolf.

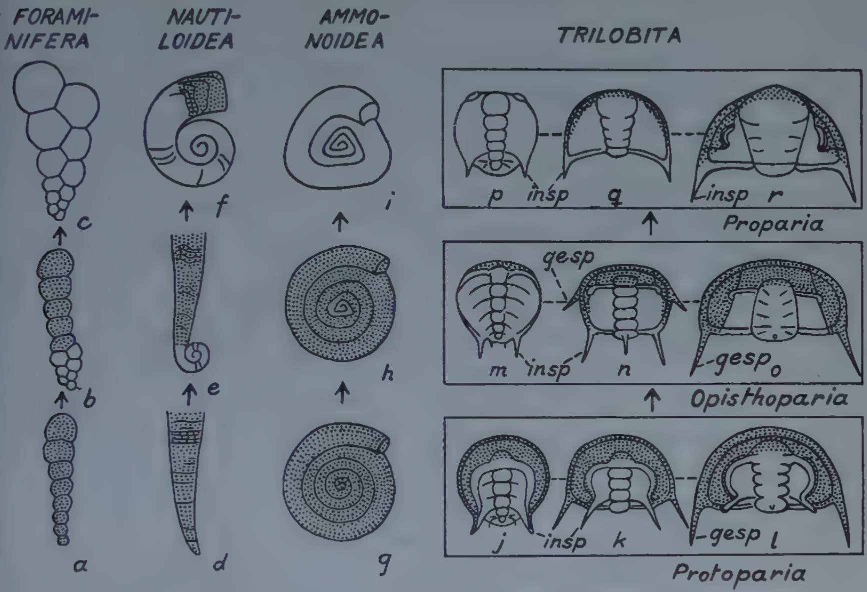


Fig. 19. The early ontogenetic appearance of new morphological characters. The new character not shaded. a = *Nodonnella*, b = *Bigenerina*, c = *Textularia*; d = *Rhynchorthoceras*, e = *Ancistroceras*, f = *Cyclolituites*; g = *Soliclymenia*, h, i = *Kamptoclymenia*; (a—i after Schindewolf); j—r = Protaspid, Meraspid and Holaspid Period of growth of *Elliptocephala* (j—l), *Olenus* (m—o) and *Dalmanitina* (p—r). *gesp* = genal spine, *insp* = intergenal spine.

The development of the coiled nautiloids from nearly straight forms is indicated in text-fig. 19 d-f. In this case the knowledge of the development is largely supported by the stratigraphical occurrences. The two first stages (d, c) occur in the same beds of the Swedish-Baltic Orthoceras Limestone (Platyrus Limestone), but the first one is also found in an older zone (Vaginata Limestone). The coiled forms occur in younger, Middle Ordovician beds (Chiron Limestone) and the typical coiled forms are common in the Upper Ordovician. The coiling of the shell thus first appears in the larval stages only and only in later forms the new character is present also in the last growth stages of the shell.

Among the ammonites Schindewolf has demonstrated an interesting development of a subtriangular shell in one group of the Upper Devonian Clymenidae. The studies are based on careful stratigraphical collections and it has been possible to distinguish several evolutionary trends. From the normal *Clymenia*-type (g) a new type differentiated, which deviates from the normal type in having a triangular outline of the earliest whorls in the shell (h). In later forms (i) the triangular whorls are not restricted to the initial portion of the shell, but comprise the entire shell which therefore deviates considerably from the ordinary *Clymenia*-type.

Schindewolf seems to have succeeded in demonstrating how a new morphological character of higher order primarily appears only in the earlier ontogenetic stages, and, since the new character is absent in the later growth stages, this is probably due to its depression by the characters inherited from the ancestors. In later phylogenetic forms the new character dominates also the later growth stages.

The presence of this evolutionary principle might also be traced in the ontogenetic and phylogenetic development of the trilobites. We might consider the retardation in the dorsal development of the preantennal segment as the new morphological character of higher order in the evolution of the trilobites. In text-fig. 18 i-r the development of the Protoparia, Opisthoparia and Proparia is indicated. The Hypoparia is not included since this group might be regarded more as an early off-shoot of the Protoparia. In contrast to the other invertebrate groups figured, the ontogeny of the trilobites cannot be studied within the shell of the adult, and three characteristic stages of development are therefore figured.

In the Protoparia the arrested development has not taken place in any of the growth stages. In the Opisthoparia, on the other hand, a distinct retardation is found in the protaspis, but already during the early Meraspid Period the preantennal segment gradually appears in a greater extent on the dorsal surface. This would mean that the characters inherited from the ancestors (the Protoparia) in later stages depress the new character. In the Proparia the preantennal segment is not at all present on the dorsal side of the protaspis, and in the Meraspid stages it is just visible in front. Even in the adult the development is arrested to such an extent that the preantennal segment does not occupy the genal angles, which evidently are formed by the pleural spines of the preoccipital segment. In this case the inherited characters have only to a small degree hampered the evolution of the new character first appearing in the early ontogenetic stages. The three trilobite orders might therefore largely be compared with the different phylogenetic stages of the other invertebrate groups illustrated in text-fig. 18.

The phylogenetic development of the Trilobita seems to illustrate the principle of evolution according to which a new character of higher order, a new type, first appears in the early larval stages and is established in the adult only in later forms.

According to this interpretation, the Proparia, with regard to this special but important character, form the most advanced trilobites. We thus arrive at the conclusion that although the opisthoparians pass through a proparian stage of development the Opisthoparia are more primitive than the Proparia. The present conception is largely supported by the stratigraphical appearance of the trilobites. The Protoparia are restricted to the Lower Cambrian. The Opisthoparia occur in all formations of the Paleozoic, but they played their most important part from the Middle Cambrian to the close of the Ordovician. The Proparia appears already in the Lower Cambrian, but the most important and typical superfamily, the Phacopidae, is characteristic of the Middle Ordovician-Devonian formations.

In general the evolution of the trilobite stock seems to a large extent to have been guided by the arrested dorsal development of the preantennal segment, a line of evolution which simultaneously was influenced by more mechanical structures such as the development of sutures in the shell.

SUMMARY OF CONCLUSIONS

1. The earliest trilobite larva, the protaspis, is known in a great number of species. The larva passes through several Protaspid stages, of which the earliest ones have a constant number of segments corresponding to those forming the cephalon in the adult. In the latest part of the Protaspid Period new segments are successively added to the primary segments. The two phases might be called the Anaprotaspid and Metaprotaspid Period of development. In more primitive trilobites several Anaprotaspid stages occur and the Metaprotaspid Period appears to the brief. In higher trilobites the first period seems to be more or less lacking (the larva might pass through these stages within the egg), and the last period contains a greater number of stages.

2. The protaspides of various trilobites differ considerably, but it is possible to distinguish and homologize the main morphological

structures characteristic of a common protaspis type. The protaspis of the Olenellidae (Protoparia) is different from those of the Opisthoparia and Proparia, and the difference is found to be due to a delayed dorsal development of the preantennal segment during the ontogeny of the latter groups. The protaspis of the Cryptolithidae is not known, but the earliest Meraspid stage indicates conditions similar to those in the Olenellidae.

3. The development of cephalic spines take place largely at a certain size of the protaspis and the degree of development seems to a considerable extent to be due to a floating habit of life. Several types of spines might be distinguished, and among these the genal and intergenal spines are the most significant. The genal spines belong to the preantennal segment, and the intergenal spines evidently belong to the preoccipital segment and are thus homologous in all known trilobite forms.

4. Previous interpretations of the cephalic segmentation have largely been influenced by the assumption of a crustacean head-plan in the trilobites. In accordance with the observed presence of one antenna and four biramous legs in the cephalon, the primitive trilobite larva has a five-segmented axis. In later stages the axis might appear as six-segmented, probably on account of a partial incorporation of the preantennal segment in front of the axis. The last segment in the anaprotaspis probably represents a true segment and not a telson. The pleuræ of the cephalic segments are directed outwards and backwards, and the preantennal, antennal and preoccipital pleuræ are more prolonged than the others. The cephalon might include the following elements: The preantennal segment complex, the antennal segment, the first to fourth leg segments. The leg segments are postoral and form the posterior primary somites differing from the secondary somites of the thorax and pygidium.

5. The transverse joints, bordering the thoracic segments in the trilobite, form an angle to the direction of the oblique pleuræ demonstrated in the protaspis. The ontogeny of *Paradoxides* and *Olenus* indicates that the first transverse suture, appearing in the first Meraspid stage, develops as a secondary suture crossing the primary segmentation. During the ontogeny the thoracic segments, which pass through the transitory pygidium and are detached as free segments in front of the latter, are regarded as containing the portions of two succeed-

ing pleuræ coalesced along the pleural furrow. The structures in *Limulus* support this conception.

6. The more mechanical interpretation of the transverse sutures between the thoracic segments might also be applied as regards the cephalic sutures. The ontogeny of the Opisthoparia and Proparia indicates that the facial suture is marginal in the protaspis. The marginal suture in the adult Olenellidae is evidently present also in the protaspis and there appears to be no real evidence of a rudimentary facial suture in the adult as claimed by most authors. Rudiments of a facial suture neither occur in the Harpidæ and Cryptolithidæ which have a marginal suture not only in the adult, but probably also in the protaspis. The marginal suture is found to be the primary cephalic suture in trilobites. The facial suture is probably homologous with the marginal suture and the different development of the cephalic sutures is evidently dependent on a rapid (Olenellidæ, Cryptolithidæ, Harpidæ) or arrested (Opisthoparia, Proparia) dorsal development of the preantennal segment in the larva.

7. The different development of the preantennal segment and the cephalic sutures seems to form a natural foundation in the classification of trilobites. The Olenellidæ probably belong to a more or less ancestral order for which Swinnerton's name Protoparia might be adopted. The order Hypoparia is provisionally maintained and regarded as comprising early offshoots of the Protoparia. The Protoparia probably gave rise to the Opisthoparia and Proparia, the latter forming the apparently most advanced trilobites.

8. The division of the Class Trilobita into four orders is due mainly to the rapid or delayed dorsal development of the preantennal segment in the larva. The arrested development or "partial neoteny" of one morphological character is found also in recent groups to be of considerable importance in forming new genera and species, Schulze has introduced the name merostasis for this principle of evolution. The conditions in trilobites might also be considered in relation to the evolutionary principle of Schindewolf according to which a new important morphological character, phylogenetically first appears in the larva and is absent in the later growth stages. In the trilobite trend of development the arrested dorsal development of the preantennal segment might be regarded as the new character which thus follows the principle demonstrated by Schindewolf.

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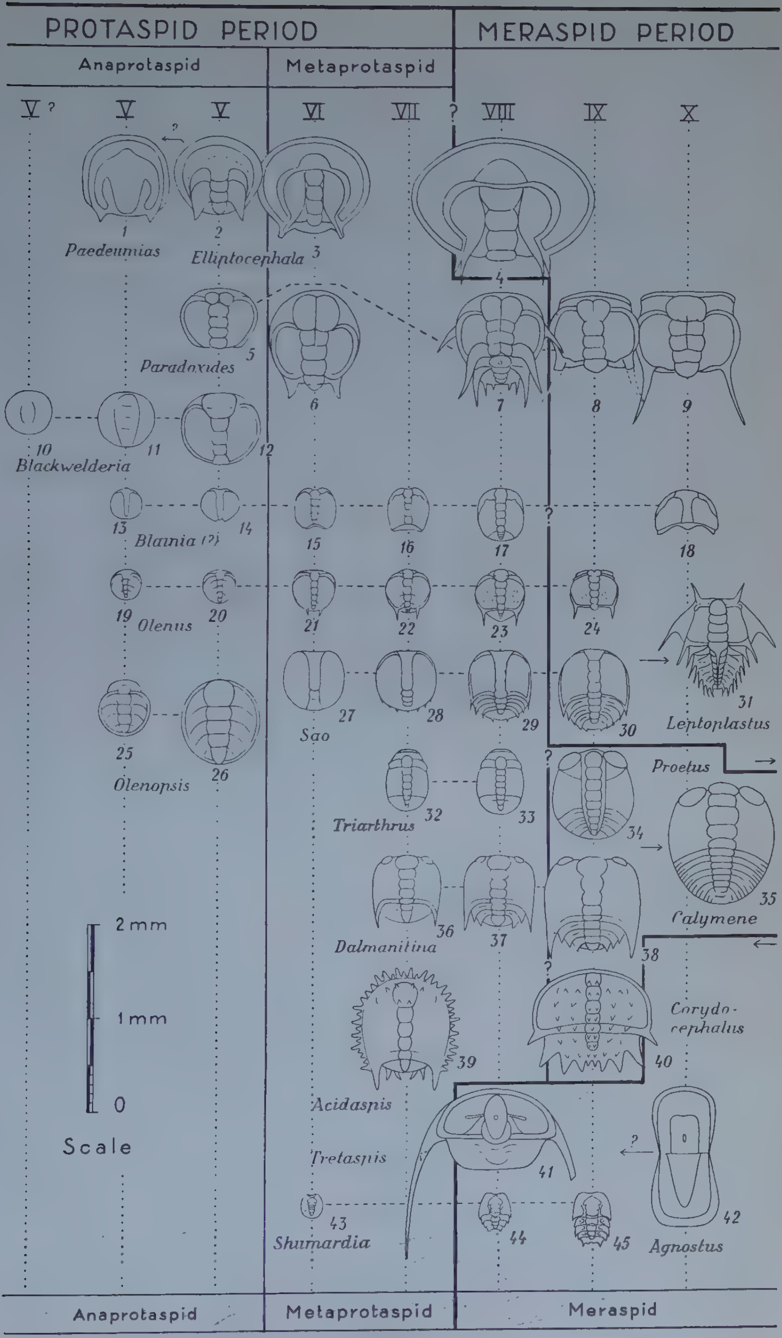
EXPLANATION OF PLATES

Plate I.

Young trilobite larvæ arranged according to their mutual stage of development. The Anaprotaspid Period comprises the stages with only primary somites (V—V). The Metaprotaspid and Meraspid Periods also include secondary somites (VI—X). As shown by the vertical line the Meraspid Period is attained at different stages of development in the various forms. Since several genera are depicted on the same horisontal line, in some cases, more than one vertical line are indicated. Fig. 31, 35 are placed too far to the left on account of the limited space. Magnification given by the scale (12×).

1=*Paedeumias hanseni* (after Pousen), *2—4*=*Elliptocephala asaphoides* (after Walcott), *5*, *7—9*=*Paradoxides pinus* (?) (after Westergård), *6*=*Paradoxides* sp. (after Raymond), *10—12*=*Blackwelderia quadrata* (after Endo), *13—18*=*Blainia gregaria* (?) (after Lalicker), *19—24*=*Olenus gibbosus* (24 after Strand), *25—26*=*Olenopsis* sp. (after Bornemann), *27—30*=*Sao hirsuta* (after Barrande), *31*=*Leptoplasus salteri* (after Raw), *32—33*=*Triarthrus* sp. (after Beecher), *34*=*Proetus parviusculus* (after Beecher), *35*=*Calymene* sp. (after Ruedemann), *36—38*=*Dalmanitina socialis* (after Barrande), *39*=*Acidaspis tuberculata* (after Beecher), *40*=*Corydocephalus consanguinensis* (after Beecher), *41*=*Tretaspis seticornis* (after Størmer), *42*=*Agnostus* (*Peronopsis*) *integer* (after Barrande), *43—45* =*Shumardia pusilla* (after Stubblefield).


PROTASPID PERIOD
MERASPID PERIOD
Anaprotaspid
Metaprotaspid
V ?
V
V
VI
VII
?
VIII
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1
Paedeumias
2
Elliptocephala
3
4
5
Paradoxides
6
7
8
9
10
11
12
Blackwelderia
13
Blainia (?)
14
15
16
17
?
18
19
Olenus
20
21
22
23
24
25
26
Olenopsis
27
Sao
28
29
30
31
Leptoplastus
?
Proetus
32
Triarthrus
33
34
35
Calymene
36
Dalmanitina
37
38
?
Corydo-cephalus
39
Acidaspis
40
Tretaspis
41
?
42
Agnostus
43
Shumardia
44
45
2 mm
1 mm
0
Scale
Anaprotaspid
Metaprotaspid
Meraspid

Plate 2.

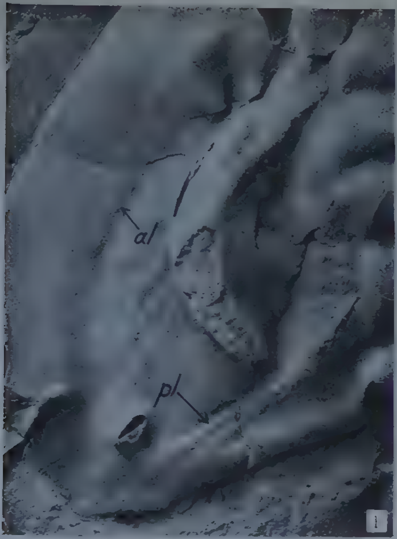
Fig. 1. *Kjerulfia lata* Kiær. 4/3 ×. Left portion of cephalon demonstrating the anterior and posterior eye lines (*al*, *pl*.). Lower Cambrian of Tømten, Ringsaker. No. 61376 Pal. Mus. Oslo Coll. (Kiær 1916 pl. 10 fig. 1).

» 2. *Liostracus linnarssoni* Brøgger (?) 20.5 ×. Metaprotaspis. Comp. text-fig. 8a. Middle Cambrian of Øxna. Brøgger coll. No. 27162 b Pal. Mus. Oslo Coll.

» 3—5. *Holmia kjerulfi* (Linnarsson). 2 ×. Fig. 3 shows the anterior and posterior eye lines (*al*, *pl*) and the intergenal spine (Kiær 1916 pl. 6 fig. 1). Comp. text-fig. 14. Fig. 4 demonstrates the relation between the occipital and thoracic pleuræ. Fig. 5 indicates the different sculpture on either side if a line leading from the lateral eye to the intergenal spine. Lower Cambrian of Tømten, Ringsaker. Nos. 22926, 22978, 23611. Pal. Mus. Oslo Coll.

» 6—7. *Holmia kjerulfi* (Linnarsson) (?). 22.2 ×. Young larva. Comp. text-fig. 4. Lower Cambrian of Tømten, Ringsaker. J. Schetelig coll. No. 22935 Pal. Mus. Oslo Coll.

The reproduced photographs are not retouched. The specimens in fig. 1, 3—5 have been whitened.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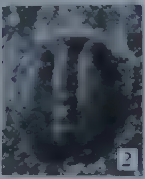
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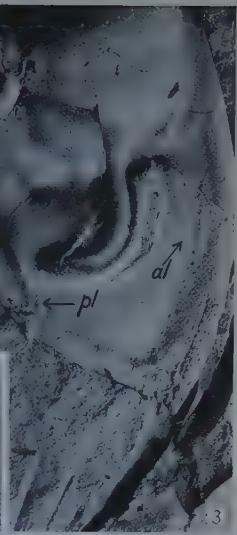
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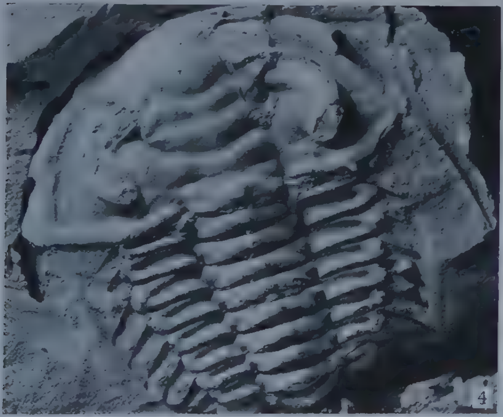
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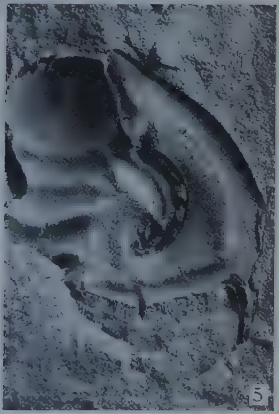
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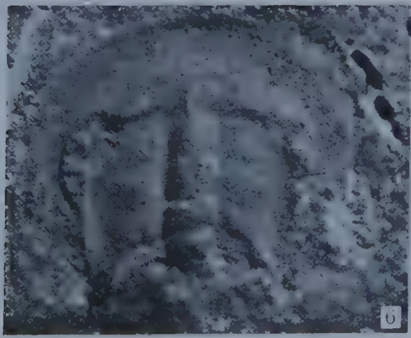
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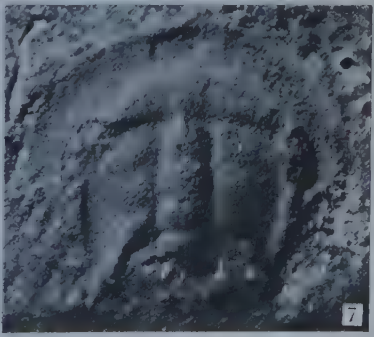
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Ms. mottatt 4. des. 1941.

OM ØIEGNEISDANNELSE I FJELLKJEDER

AV

IVAN TH. ROSENQVIST

MED 5 FIGURER

Forord: Det foreliggende arbeide er et referat av et foredrag holdt i Norsk geologisk forening 4. des. 41. Det omhandler den metasomatiske øiegneisdannelse, som efter forfatterens mening har vært virksom blandt annet langs Trondheimsfeltets vestkant. Arbeidet er et resultat av feltarbeide utført for og med støtte av Norges geologiske Undersøkelse mens laboratoriearbeidet er utført ved Universitetets mineralogiske institutt med støtte av »Det videnskabelig forskningsfond av 1919«. Jeg takker herved disse institusjoner.

De vanlige teorier for øiegneisdannelse er den porfyroklastiske og den porfyroblastiske. Ved porfyroklastiske øiegneiser forstår en øiegneiser dannet av en porfyrisk bergart ved at mellemmassen mylonittiseres og omkrystalliseres, mens fennokrystallene består som sådanne i lite omdannet form.

Dette var tidligere den vanlige opfatning av øiegneisene, og en del av de øiegneiser en finner er sikkert dannet på denne måte.

Den dannelsesmåte som imidlertid har vært den viktigste er den porfyroblastiske, der særlig feltspat»øiner« er dannet ved at enkelte feltspatkrystaller vokser på bekostning av annet tilstedeværende feltspatmateriale.

En slik porfyroblastese kan skje enten under tilførsel av stoff, som en metasomatisk porfyroblastese eller uten noen stofftilførsel bare ved en metamorf differensiasjon innen bergarten. (Eskola 1932.)

De forhold jeg her vil berøre er især de som angår dannelsen av de grove øiegneiser en har langs Trondheimsfeltets vestkant mellem Drivstua og Troldheimen og også langs vestkanten av »Surnadalsfliken«. Disse øiegneiser er flere ganger nevnt i litteraturen av: Törnebohm 1896, K. O. Bjørlykke 1905, V. M. Goldschmidt 1915 og 1916 samt flere ganger av C. W. Carstens 1922 og 1925 a og b. Dessuten har nylig Holtedahl 1938 og jeg 1941 nevnt disse bergarter.

Dette foredrag behandler da særlig mitt syn på disse gneisers dannelse og er et ledd i en nærmere undersøkelse over metamorfosen i Opdalområdet. Dog kan det hende jeg kommer med enkelte betraktninger over øiegneisdannelse i sin almindelighet, som jeg ikke kan bevise har foregått ved Opdal.

Ser en på øiegneisene som en har dem ved Engan—Drivstua har en en mineralparagenese med kalifeltspat — albittoligoklas — klinozoisitt — kvarts — biotitt — hornblende — og ofte granater. Denne paragenese tilsvarer en forholdsvis lav likevektstemperatur antagelig ca. 300° og en skulde da ha et trykk rundt om 20 000 atm. Dette vil si, at en har et PT-område der en har ekte vandige opløsninger og en slipper regne med overkritiske fluide faser.

Hvorledes de bergartsdannende mineralers fysikalske kjemi er ved disse betingelser, er ikke blitt laboratoriemessig undersøkt. R. Goranson[1] har i flere arbeider behandlet systemet granittsmelte vann og feltspatsmelte vann, under forskjellige trykk og temperaturforhold, men da han her ikke har temperaturer vesentlig under 600° kommer disse arbeider ikke til å ha noen særlig betydning når det gjelder øiegneisenes dannelse. Han angir imidlertid følgende som kan ha betydning ved spekulasjoner over øiegneisenes dannelse ved disse lave temperaturer. »En må søke å ha så lite overskudd av vann som mulig da det ellers vil skje en utlutning av silikatene, og dermed en forrykning av de kjemiske forhold.« Han mener — Geophysical Laboratorys publ. 908 — at en av det overskytende vann ved en albitt-vann-smelteløsning har fått utkrystallisert leverieritt (et vannholdig aluminiumsilikat). At imidlertid også feltspat lett kan krystallisere ut av slike opløsninger viser følgende eksperiment som jeg har utført sammen med dr. Ernst Føyn under hans arbeide med kunstig forvitring av uranmineraler (hittil upublisert):

I et Jena synteserør blev uraninitt ophetet til 200 og 300° inntil 12 timer med et par ml destillert vann. Efter avkjøling viste det sig at glasset i røret var sterkt forvitret og på uraninittkrystallen fantes en mengde optil 1½ mm lange klare farveløse krystaller, som i alle sine optiske egenskaper viste sig å være identisk med ren albitt.

Vannet i røret hadde da en meget sterk alkalisk reaksjon, pH optil 10,7.

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[1] En del av disse arbeider finnes nevnt i litteraturlisten.

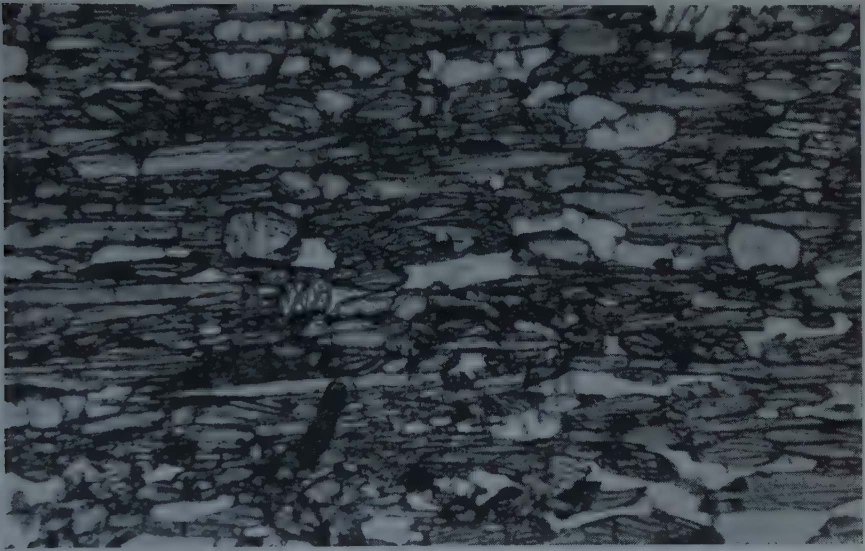

Fig. 1. Hornblendeskifer med små feltspatindivider.
50 × forst. ÷ Nicol.

Analyse av glasset:

(Stud. real. Gerd Lystad.)

SiO_2	75,58	MgO	0,42
TiO_2	—	CaO	3,26
Al_2O_3	4,74	Na_2O	2,08
Fe_2O_3	sp.	K_2O	3,93
FeO	sp.	BaO	1,30
MnO	sp.	B_2O_3	7,30
		Sum	98,61

Jeg har tidligere vist at ved utlutning av granittisk bergart med vann ved vanlig temperatur, får en en sterk anrikning av alkali og kalsium i opløsning, mens også aluminium og kiselsyre var til stede, og det i mengde som overgikk opløseligheten for de rene oksyder i vann.

Det synes således å være klart, at det første som skjer når vann innvirker på en bergart ved ikke for høie temperaturer er at enkelte av mineralene, og da i første rekke glimmer og feltspat hydrolyseres, og at en får en vandig lut som så i sin tur har evnen til å løse kiselsyre og lerjord under dannelse av silikater og aluminater.

Hvilken innflytelse trykk og temperatur har på en slik opløsning er ikke undersøkt, men da jo opløsningens innhold av kiselsyre respektive lerjord er en funksjon av opløsningens innhold av alkali og også antagelig av jordalkali, kan en finne meget ut angående opløseligheten av silikatene ved å undersøke opløselighetsforholdene for alkalijordalkalimetallenes forbindelser under varierende trykk og temperatur. R. E. Gibson (1938) har undersøkt opløselighetsforholdene for en rekke stoffer under forskjellige trykk og temperaturforhold. En har følgende ligning for variasjonen av en mettet opløsnings kjemiske potensial som funksjon av konsentrasjon og trykket:

$$\frac{d\mu}{dX} = \frac{({V_2}^s \div V)\delta P}{\partial X} k$$

derav følger

$$\frac{dX}{dP} = \div \frac{V \div {V_2}^s}{\left(\frac{\delta\mu}{\delta X}\right)_{PT}} \cdot K$$

hvor X er konsentrasjonen av en mettet opløsning, P er trykket, V er partialvolumet av det opløste stoff i opløsningen. ${V_2}^s$ er det spesifikke volum i fast fase og $\frac{d\mu}{dX}$ er opløsningens kjemiske potensials variasjon med hensyn på konsentrasjonen ved eksperimentets temperatur og trykk. Da $\frac{d\mu}{dX}$ alltid er positivt, blir $\frac{dX}{dP}$ positivt når ${V_2}^s$ er større enn V.

Gibson viser ved eksperimenter at det bare i sjeldnere tilfelle finner sted en økning av opløseligheten ved økende trykk.

Dette er forsåvidt en lenge kjent ting, derimot viser han at *karbonater, sulfater, sulfider, fluorider og hydroksyder av en del alkalimetaller og kalsium blir mer løselig ved økende trykk.* Det er altså nettop de forbindelser som kan tenkes å virke opløsende på kiselsyre og lerjord. Nu kjenner en ikke surere aluminater enn NaH_2AlO_3, mens en antar det eksisterer meget sure alkalisilikater som f. eks. $NaH_3Si_4O_{10}$ og enda surere forbindelser.

Under avkjøling og synkende trykk kan en av slike opløsninger få utskilt *ren kiselsyre slik en finner det i de hydrotermale kvartsganger.* Det er også selvinnlysende at de hydrotermale kvartsganger ikke kan være avsatt av rene vandige kiselsyreopløsninger da jo kiselsyre er meget lite opløselig i vann, selv ved et par hundre grader

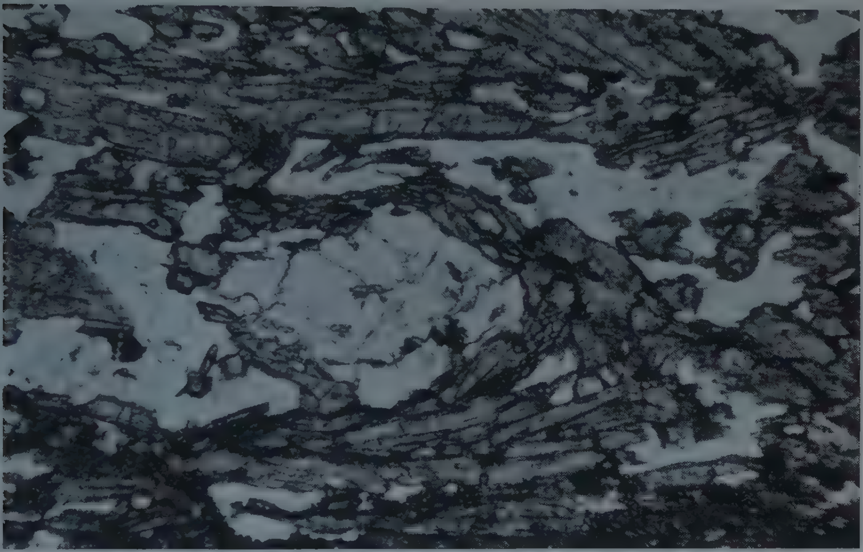

Fig. 2. Hornblendeskifer med feltspat porfyroblast.
50 × forst. ÷ Nicol.

og flere hundre atmosfærers trykk. En slik opløsning vilde dessuten øieblikkelig hydrolysere sidestenens mineraler og opta alkali og jordalkalier fra disse.

I øiegneisene ved Drivstua har som eldste mineral i porfyroblastene en saussurittisert plagioklas og yngre mikrolin. Plagioklasen finnes til dels som rundede inneslutninger av omdannet plagioklas med en kappe av albitt og kvarts i mikropertitt. På spalter i mikroklinen har en svakt undulerende kvarts. Saussurittiseringen av plagioklasen behøver ikke bety at denne er av nevneverdig større alder enn de andre mineraler, men er vel snarere å opfatte som en autosaussurittisering.

De eldre opfatninger av øiegneisene rundt Trondheimsfeltet[1] kan neppe være riktige da en i disse sterkt forgneisede bergarter finner de utpreget »rapakivi«aktige bergarter som Carstens og V. M. Goldschmidt har vist finnes ved Drivstua, og som Carstens ganske riktig har vist helt gradvis går over i vanlig grov øiegneis og andre bergarter. Det skulde synes innlysende at en bergart som »rapakivisyenitten« ved Drivstua med sine store runde og kantede feltspatøiner med størrelse op til 5 cm ikke kan ha vært utsatt for de samme prosesser som har presset det sparagmittiske bunnkonglomerat ut nesten til det ugjenkjennelige få kilometer borte. Samtidig må en bemerke at grunnmassen i »rapakiviene« er *sterkt forgneiset.*

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[1] A. E. Törnebohm opfatter øiegneisene som overskjøvne dekker av grunnfjellsbergarter av porfyrisk oprinnelse. Det centrale Skandinaviens Bergbygnad 1869. — — — K. O. Bjørlykke opfatter øiegneisene som yngre kambrosiluriske (kaledonske) intrusiver og ekstrusiver som i flytende tilstand skulde være kommet på sin nuværende plass. Det centr. Norges fj.bygn. 1905. V. M. Goldschmidt, Højfjeld IV, fører dem op under berg-

Da som nevnt feltspat lett kan krystalliseres ut av en vandig alkalialuminiumsilikatopløsning, har en bare å undersøke aluminiums opløselighet. Aluminium vil nemlig være den minimumsfaktor i opløsningen som bestemmer hvor meget feltspat det kan dannes.

Aluminiums opløselighet er vesentlig avhengig av opløsningsmidlets pH og da en efter det foran anførte får mer alkali opløst ved økende temperatur og økende trykk får en altså mer aluminium opløst ved økende trykk under konstant temperatur. En har her helt analoge forhold ved den tekniske fremstilling av Al_2O_3 etter Bayerprosessen.

Da en således ser at *feltspatenes løselighet stiger med økende trykk* ser en det unaturlige i at feltspatporfyroblaster og kvartsporfyroblaster skal dannes under en fjellkjedes nedfoldning. Derimot vil dannelsen kunne finne sted fra den maksimale nedfoldnings tid og videre under denudasjonen når trykket respektive temperaturen avtar. En ser her en forklaring på porfyroblastenes øiestruktur. Da porfyroblastene altså gror i en forgneiset bergart vil motstanden mot en krystallvekst være størst loddrett på skifrigheten og minst parallelt med denne.

Da altså *opløseligheten blir større loddrett på skifrigheten enn parallelt med denne* vil en ellipsoidelignende struktur på porfyroblastene være det naturlige resultat. Da samtidig løseligheten av et mineral er forskjellig efter de forskjellige krystallografiske akser vil krystallene legge sig slik orientert at en bestemt krystallografisk

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arter av ukjent stamme, men synes mest å helle til en opfatning som tilsvarer Bjørlykke. Han nevner også den nøie sammenheng med rapakiviene ved Drivstua. C. W. Carstens er den som mest har beskjeftiget sig med øiegneiser i Opdalområdet. Han opfatter øiegneisene som metamorfoserte prekambriske eruptive rapakivigranitter, idet han antar at rapakivistrukturen er en primær porfyrstruktur.

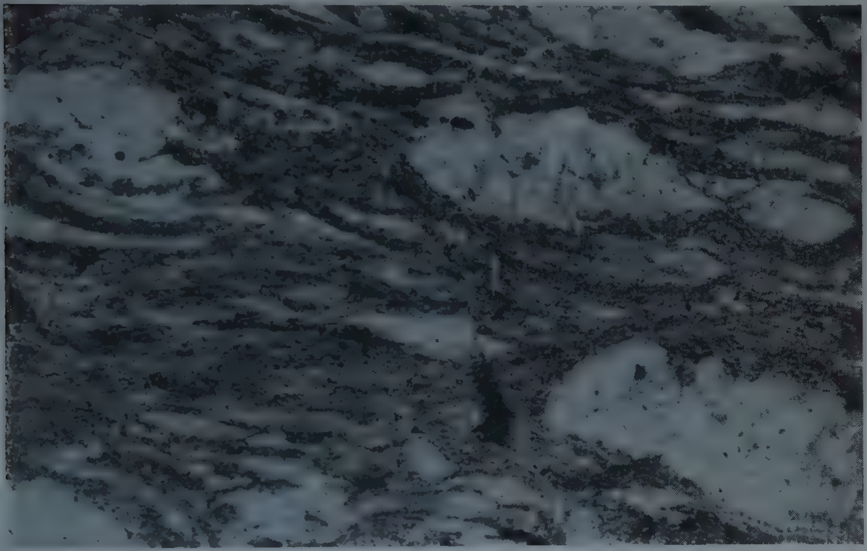

Fig. 3. Øiegneis fra Rise. 1 × nat. størrelse.

akse tar samme orientering i bergarten. Dette finner en da også stort sett for alle kvarts- og feltspatporfyroblaster.

Da aluminium er den komponent som først vil utskilles ved trykkavlastning og synkende temperatur, har en *en* faktor som skulde bidra til at aluminiumrike plagioklaser først skulde utskilles av de hydrotermale opløsninger. Samtidig viser alle forsøk at basisk plagioklas er den feltspat som lettest hydrolyseres,[1] og dette skulde virke i motsatt retning.

Det blir derfor opløsningens kjemiske sammensetning som kommer til å avgjøre om en skal få utkrystallisert en normal sonarbygget plagioklas eller en invers sonarbygget plagioklas. Til sist vil en få utkrystallisert kvarts og det overskytende kalsium som kalkspat.

Efter det foran anførte, og hvad som senere skal bli mer begrunnet anser jeg dannelsen av de grove øiegneiser som en metasomatisk prosess. Utgangsmaterialet var antagelig basiske intrusiver og lavaer tilhørende opdalitt-trondheimittstammens bergarter. Disse skulde så ved en kalimetasomatose omdannes fra kloritt-hornblendeskifer til biotitt-hornblendeskifer og i denne blev ved øket tilførsel av et kalivannglass dannet enkelte mikroklin porfyroblaster som med tiltagende mengde bragte bergarten over til øiegneisstadiet. Det siste som fant sted var en utstrakt omdannelse av hornblenden til biotitt ved en kalitilførsel. Det således frigjorte kalsium finner en da igjen i »rapakivienes« albitt-oligoklas kappe.

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[1] Denne hydrolyse resulterer ved lav temperatur i en utlutning av kalk og et bauxittlignende residium. Ved økende basisitet av opløsningen vil mere aluminium gå i opløsning inntil en ved bestemt kalk-alkalimengde vil få en opløsning som står i likevekt med en bestemt plagioklas. Ved synkende temperatur og trykk vil en av en slik opløsning få utkrystallisert den plagioklas som er i likevekt med opløsningen, mens opløsningen stadig blir aluminiumfattigere og kommer i likevekt med en surere plagioklas.

En støtte for en slik teori har en bl. a. i de forhold at hornblenden i øiegneisene, og som Carstens også har observert i »rapakiviene« er uraliter, til dels kan en sogar finne pene pyroxenkjerner som endog tillater å fastslå de optiske data svarer til en lys hypersten. Dels kan en finne hornblender som fra kantene er omdannet til biotitt og dels biotittaggregater med hornblendekjerne.

Denne opfatning av øiegneisproblemet slutter sig i mangt og meget til den opfatning som Backlund hevder i sitt arbeide, The Problems of the Rapakivi Granites (1938). Han fremsetter her den opfatning at rapakivigranittene i Finland og Sverige skulde være dannet ved en granitisiasjon av jotnisk sandsten. Hvad angår rapakiviene ved Drivstua behandler han ikke disse da de skiller sig fra de svenske og finske ved, som han sier å være kaledonsk metamorfosert.

Som felles trekk ved alle de rapakivier han behandler har en at de er posttektoniske. Dette er nøiaktig hvad jeg mener også er tilfelle med øiegneisene ved Opdal. Backlund anfører at de femiske oksyder har holdt sig konstant under migmatiseringen.

At Backlund deriverer rapakiviene fra de jotniske sandstener og at jeg mener at øiegneisene stammer fra norittiske lavaer gjør ingen forskjell for tankeutviklingen. En har da også at øiegneisene er betydelig mer femisk betonet enn de ekte rapakivier. Backlund mener også at en del grove monzonittiske bergarter som optrer i nærheten av og sammen med rapakiviene er dannet ved en lignende prosess fra gabbroide bergarter, loc. cit., p. 383.

Som en vil se av de analyser Backlund anfører har også hos ham den innvandrede emanasjon vært særlig kalibetonet. Dette gjelder ikke så meget angivelsene fra Dalaporfyrene som han anser som rapakivienes vulkanske facies, og som skulde være dannet av jotnisk sandsten, slik en finner den i Hamraområdet i Dalarne.

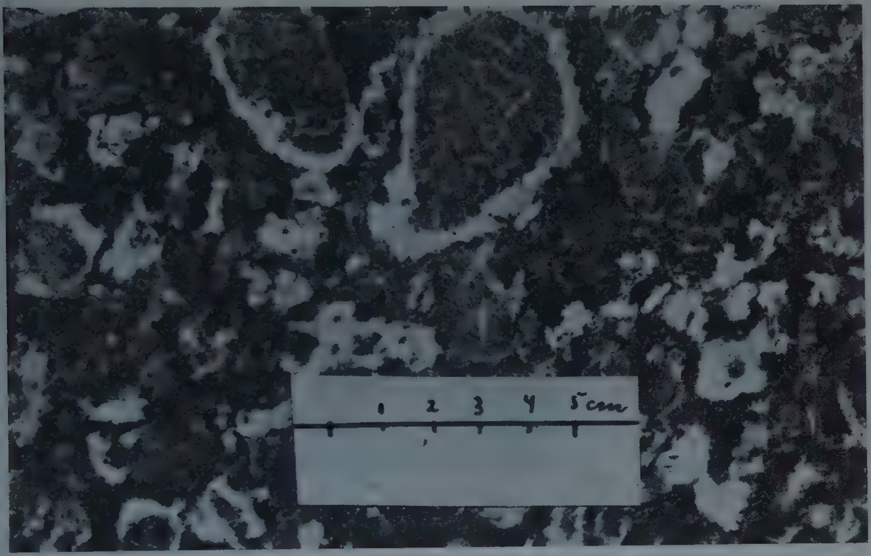

Fig. 4. Rapakiviaktig øiegneis fra Drivstua.

For de finske rapakiviene fra Viborgområdet derimot, er kalitilførselen betydelig. Denne forskjell synes vesentlig å skyldes at Dalasandstenen er meget kalirik, mens Svir-sandstenen mellem Ladoga og Onega er meget kalifattig.

Det er foruten den store forskjell i utgangsbergarten ved dannelsen av øiegneisene og rapakiviene en utpreget forskjell i den temperatur hvorved omdannelsene har funnet sted. For rapakivienes vedkommende har en temperaturer over det granittiske eutektikum, slik at en stor del av bergarten har vært i flytende tilstand, noe som har resultert i at rapakiviene har fått en betydelig mer eruptiv karakter, men som Backlund anfører har en flere trekk ved rapakivigranittene som er nedarvet fra de jotniske sandstener.

Som anført av V. M. Goldschmidt har øiegneisene ved Opdal en kjemisk sammensetning som gjør at de ikke kan henføres i noen av de i den kaledonske fjellkjede vanlige bergartsstammer. Dette harmonerer også utmerket med det kjente forhold at rapakivigranittene ikke lar sig henføre til noen vanlig differensiasjonsstamme. Også v. Eckermans[1] angivelser av overgangsledd basalt — rapakivi, viser at en metasomatose av basalter også gir rapakivilignende bergarter. Dette er Backlunds tolkning av de analyttiske resultater Eckerman angir. Backlunds opfatning har som kjent blitt sterkt kritisert av bl. a. V. Eckerman. Allerede i 1928 viste Barth, Chemie der Erde, p. 95—136, at en i Kristiansandområdet har en metasomatisk utvikling fra amfibolitt til øiegneis. Den amfibolitt det der er tale om er riktignok igjen et skritt i den migmatiske utviklingsrekke som fører fra kalksten via skarn, amfibolitt — øiegneis til lys gneis — pegmatitt, men det må bli det samme enten amfibolitten er en metasomatisk omvandlet marmor eller den er en uralitisert noritt-porfyritt. De forhold som Backlund og Barth behandler skiller sig fra øiegneisdannelsen ved Engan ved en betydelig høiere temperatur. Barth angir ca. 500°, noe som gir sig uttrykk i plagioklasens høiere anortittinnhold. Backlund nevner at plagioklaskapper rundt mikroklinene, øinene i rapakiviene kan opfattes som eldre krystaller skjøvet til siden under feltspatenes vekst. Da plagioklasene rundt og i feltspatøinene ved Engan optrer meget på samme måte som ved de finske rapakivier (Viborgittene) er en lignende tolkning også mulig i Opdalfeltet, men det er også adskillige forhold som taler for at plagioklas og kalifeltspat er dannet på noenlunde samme tid. *Felles for alle øiegneislignende bergarter er deres postorogene oprinnelse* og mange forskjellige tolkninger av såvel rapakiviene som øiegneisproblemet kan ikke bortforklare dette felles trekk.

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[1] The Jotnian Formation and Sub-Jotnian Unconformity. Geol. Pos. First Vol. LIX (1937). P. 19—59.

En ting som viser hen på den høiere temperatur ved rapakivienes dannelse er de store fluormengder som finnes i disse bergarter og som gir hele omvandlingen et mer pneumotolyttisk anstrøk. I Opdalfeltets bergarter er fluormineraler helt underordnet og fluorinnholdet må for det aller vesentligste ansees bundet i hornblende, biotitt og apatitt. Noen fluor migrasjon kan ikke sees å ha funnet sted i Opdalsfeltet, når det derimot som anført av v. Eckerman ved Backlunds granittisering av de jotniske sandstener har deltatt imigrerende opløsninger med 7pct. fluor er dette noe som tydelig skiller migmatiseringen i rapakiviområdene fra den hydrotermal metasomatiske omvandling i Opdals øiegneisområde. Forskjellen betinges vel vesentlig av den betydelige forskjell i reaksjonstemperaturen og er av mindre betydning for selve reaksjonsmekanismen.

Carstens er inne på den tanke at det er foregått en metasomatisk forandring ved en metamorfose av rapakiviene til øiegneiser. Denne metasomatiske forandring skulde imidlertid være av den art at det

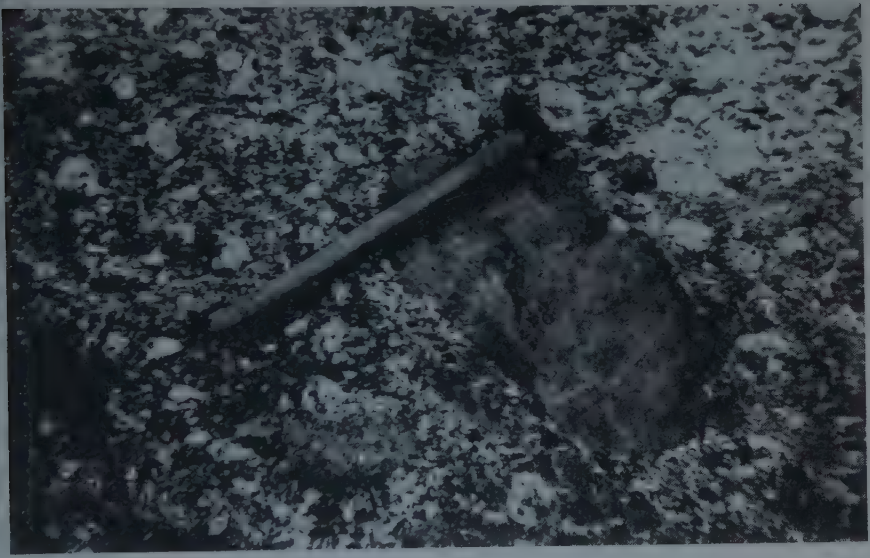

Fig. 5. Øiegneis med rester av uomvandlet amfibolitt syd for Gråhø.

skjedde en vesentlig tilførsel av jernmagnesium o. s. v. og at alkaliene blev holdt konstant. En slik antagelse er ikke sannsynlig, og også her ser en støtte for den omvendte antagelse at rapakiviene er en videre utvikling av øiegneisene ved den samme metasomatiske prosess.

For å illustrere den metasomatose jeg mener har foregått ved øiegneisenes dannelse fører jeg her op et bilansregnskap ut fra den forutsetning at utgangsmaterialet har vært en lava svarende til kvarts-biotitt Noritten fra Gissenåsen,[1] som Goldschmidt anfører som et femisk ledd i Opdalitt trondheimittstammens differensiasjonsrekke og at summen summen av Fe^{++} og Fe^{+++}har holdt seg konstant under prosessen. Jeg vil ikke dermed påstå at de lavaer som er metasomatisk omvandlet har hatt nøyaktig denne sammensetning; men da gabbroide bergarter er av temmelig analog sammensetning hvilken eruptivstamme de måtte tilhøre og en i Gråhø sausurittgabbro har bergarter av temmelig samme sammensetning, velger jeg dette utgangspunkt.

Den mulighet at en injeksjonsmetamorfose av en granitt i grønnskiferne har bevirket øiedannelsen forutsetter for å senke

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[1] Forkortet Q. B. Nor.

Gråhø gabbro.

Q. B. Nor. Gissenås V. M. G.		Gråhø gabbro I. Th. R.		Omregnet til 10,26 pct. Fe tot.	Tilført	Vekkført
SiO_2 51,67		SiO_2 51,96		53,00	SiO_2 1,33	-
TiO_2 1,82		TiO_2 1,00		1,02	TiO_2 -	0,80
Al_2O_3 15,42		Al_2O_3 16,84		17,15	Al_2O_3 1,73	-
Fe_2O_3 1,04	10,26	Fe_2O_3 3,35	10,08	-	Fe_2O_3 -	-
FeO 9,32		FeO 7,08		10,26	FeO -	-
MnO 0,14		MnO i. b.		-	MnO -	-
MgO 7,13		MgO 5,24		5,33	MgO -	1,80
CaO 8,54		CaO 8,22		8,38	CaO -	0,18
Na_2O 2,98		Na_2O 2,91		2,97	Na_2O -	0,01
K_2O 0,92		K_2O 1,71		1,74	K_2O 0,80	-
H_2O 0,59		H_2O 1,34		-	H_2O -	-

Trondheimskifer fra Tilsethaugen.

Q. B. Nor.		Trondheimskifer med albitt-porfyroblaster I. Th. R.		Omregnet til 10,26 pct. FeO tot.	Tilført	Vekkført
SiO_2 51,67		SiO_2 55,50		55,55	SiO_2 4,88	-
TiO_2 1,82		TiO_2 1,52		1,52	TiO_2 -	0,30
Al_2O_3 15,42		Al_2O_3 15,89		15,91	Al_2O_3 0,49	-
Fe_2O_3 1,04	10,26	Fe_2O_3 3,64	10,25	-	Fe_2O_3 -	-
FeO 9,32		FeO 7,02		10,26	FeO -	-
MnO 0,14		MnO 0,20		0,20	MnO 0,01	-
MgO 7,13		MgO 6,52		6,52	MgO -	0,51
CaO 8,54		CaO 4,85		4,85	CaO -	3,71
Na_2O 2,98		Na_2O 2,05		2,05	Na_2O -	0,93
K_2O 0,92		K_2O 2,21		2,21	K_2O 1,29	-
H_2O 0,59		H_2O÷ 0,18		0,18	HO_3÷ -	-
H_2O		H_2O+ 1,02		1,02	H_2O+ 0,61	-
		Sum 100,60				

Diabas fra Storhaug.

Q. B. Nor.		Diabas Storhaug I. Th. R.		Omregnet til 10,26 pct. FeO tot.	Tilført	Vekkført
SiO_2 51,67		SiO_2 57,02		65,30	SiO_2 13,63	-
TiO_2 1,82		TiO_2 0,98		1,12	TiO_2 -	-
Al_2O_3 15,42		Al_2O_3 16,93		19,35	Al_2O_3 3,93	-
Fe_2O_3 1,04	10,26	Fe_2O_3 3,61	8,95	-	Fe_2O_3 -	-
FeO 9,32		FeO 5,71		10,26	FeO -	-
MnO 0,14		MnO 0,16		0,18	MnO -	0,01
MgO 7,13		MgO 2,12		2,46	MgO -	4,67
CaO 8,54		CaO 4,68		5,37	CaO -	3,09
Na_2O 2,98		Na_2O 3,25		3,72	Na_2O 0,74	-
K_2O 0,92		K_2O 4,36		5,00	K_2O 4,06	-
H_2O 0,59		H_2O 1,20		-	H_2O -	-

Øiegneis fra Rise gård

Q. B. Nor.			Øiegneis Rise I. Th. R.			Omregnet til 10,26 pct. FeO tot.	Tilført		Vekkført
SiO_2	51,67		SiO_2	60,79		71,52	SiO_2	19,85	-
TiO_2	1,82		TiO_2	0,22		0,26	TiO_2	-	1,5
Al_2O_3	15,42		Al_2O_3	15,99		18,80	Al_2O_3	3,38	-
Fe_2O_3	1,04	10,26	Fe_2O_3	4,54	8,73	10,26	Fe_2O_3	-	-
FeO	9,32		FeO	4,65		-	FeO	-	-
MnO	0,19		MnO	-		-	MnO	-	-
MgO	7,13		MgO	2,24		2,64	MgO	-	4,47
CaO	8,56		CaO	2,11		2,48	CaO	-	6,08
Na_2O	2,98		Na_2O	2,22		2,61	Na_2O	-	0,27
K_2O	0,92		K_2O	5,69		6,70	K_2O	5,78	-
H_2O	0,59		H_2O	1,02		1,20	H_2O	0,61	-

Øiegneis fra Broen ved Rise.

Q. B. Nor.			Øiegneis Broen ved Rise Op. 4 (Bruun)			Omregnet til 10,26 pct. FeO tot.	Tilført		Vekkført
SiO_2	51,67		SiO_2	60,97		76,10	SiO_2	24,43	-
TiO_2	1,82		TiO_2	1,61		2,00	TiO_2	0,18	-
Al_2O_3	15,42		Al_2O_3	14,61		18,18	Al_2O_3	4,76	-
Fe_2O_3	1,04	10,26	Fe_2O_3	2,54	8,36	-	Fe_2O_3	-	-
FeO	9,32		FeO	6,07		10,26	FeO	-	-
MnO	0,14		MnO	0,14		0,18	MnO	0,04	-
MgO	7,13		MgO	1,54		1,95	MgO	-	5,18
CaO	8,54		CaO	3,76		4,72	CaO	-	4,82
Na_2O	2,98		Na_2O	3,36		4,29	Na_2O	1,22	-
K_2O	0,92		K_2O	3,85		4,82	K_2O	3,90	-
H_2O	0,59		H_2O	1,04		1,30	H_2O	-	-

Rapakivi Drivstua (Carstens).

Q. B. Nor.			Rapakivi Drivstua (Carstens)			Omregnet til 10,26 pct. FeO tot.	Tilført		Vekkført
SiO_2	51,67		SiO_2	63,45		129,80	SiO_2	78,13	-
TiO_2	1,82		TiO_2	0,97		1,91	TiO_2	0,15	-
Al_2O_3	15,42		Al_2O_3	16,18		32,80	Al_2O_3	17,38	-
Fe_2O_3	1,44		Fe_2O_3	1,32	4,95	2,67	Fe_2O_3	-	-
FeO	9,32	10,26	FeO	3,77		10,26	FeO	-	-
MnO	0,19		MnO	0,11		0,22	MnO	0,03	-
MgO	7,13		MgO	1,00		2,03	MgO	-	5,10
CaO	8,56		CaO	3,36		6,82	CaO	-	1,74
Na_2O	2,98		Na_2O	3,85		7,80	Na_2O	4,82	-
K_2O	0,94		K_2O	4,60		9,33	K_2O	8,39	-
H_2O	0,59		H_2O	0,60		-	H_2O	-	-

MgO-gehaltene fra 7,13 i Q. B. Nor. til 1,00 i rapakiviene, en granittmengde på ca. 1000 pct. og for å få dannet øiegneisene ved Rise ca. 400 pct. Slike granittmengder vilde imidlertid ikke kunde bringes i overensstemmelse med de store jernmengder som ennu finnes i øiegneisen beregnet som Fe_2O_3 har en 8,73 pct. Rise I. R. og 8,36 pct. i Broen ved Rise. Dette forutsetter bare granittmengder av størrelsesordenen 50 pct. Det faller derfor helt naturlig å anta at det har immigrert vannglasslignende opløsninger, og da i første rekke kalivannglass, og at disse har frigjort de svakere baser, magnesium og kalsium. Dette blir en analog metasomatose til de prosesser som V. M. Goldschmidt forutsetter i Stavangerfeltet.

Han er der i tvil om hvorvidt øiegneisene i Stavangerfeltet skal opfattes som migmatisk omvandlede pelittiske sedimenter eller kataklastiske intrusiver, og anfører en rekke argumenter for den første antagelse, men lar spørsmålet stå uavgjort. De samme argumenter som han i Stavangerfeltet taler for en migmatisk oprinnelse for øiegneisen har en også i Opdalsfeltet ved siden av en mengde andre sterke indisier. Det synes dog også i Stavangerfeltet å ha hersket en smule høiere temperatur enn i Opdal, i et hvert fall er bergartene der en del tørrere enn de tilsvarende Opdalsbergarter.

Den petrografiske beskrivelse som V. M. Goldschmidt gir av øiegneisene i Stavangerfeltet viser til sine tider en rent forbløffende likhet med bergartene fra Engan. Det vil jo også i så sterkt omvandlede bergarter som migmatiske øiegneiser, være omtrent likegyldig hvilket utgangsmateriale en starter på enten det er palittisk sediment eller intermediær — basisk lava. Det avgjørende vil bli de reaksjoner som har funnet sted, og de termodynamiske forhold disse har funnet sted under.

En kan ikke i de hydrotermalmigmatiske bergarter, mer enn i andre migmatitter direkte gjenkjenne utgangsmaterialene og det blir den geologiske optreden som sammen med de kjemiske data som blir de avgjørende argumenter.

Omkring Tronfjellets topp og i Trondalen ved Skoremsetrene finner en en lys muscovitt øiegneis som klart henger sammen med helleserien, og det synes for mig som om disse lyse øiegneiser, som en for øvrig også finner ved Furunes ved Albu (tidligere publ.) loc. cit. skyldes en porfyroblast dannelse i hellene. Her trenger en imidlertid ikke noen tilførsel av alkali og porfyroblastdannelsen blir mest å opfatte som en omkrystallisasjon.

Hvor de alkalimengder stammer fra som er medgått til øiegneismetasomatosen kan en ikke uten videre si en har mulighetene for at de kan stamme fra Trondhjemittenes vandige restopløsninger eller at de kan være lutet ut av det sparagmittiske materiale som danner hellestenen.

Summary.

The origin of the coarse augengneisses bordering the western parts of the Trondheim area is discussed. As examples are chosen augengneisses in the Opdal area and "rapakivi" syenitic rocks by Drivstua. These rocks are regarded as metasomatically changed effusive rocks belonging to the Opdalite—Trondheimite rock series.

The chemical changes induced in the rock can be called a potash metasomatism. It was analogous to the soda-metasomatism in the Stavanger area described by V. M. Goldschmidt, and similar to the processes which according to Backlund's opinion effected the origin of the rapakivi granites in Finland and Sweden.

Moreover the mode of origin of feldspar porphyroblasts is discussed. It is made reasonable that the feldspar porphyroblasts are formed as anti-stress minerals in post-orogenic time. Hence the coarse augengneisses should be interpreted as post- or late-Caledonian hydrothermal migmatites. This is in good accordance with the fact observed that the rocks are very coarse-crystalline and that insignificant traces of pressure can be found, this in spite of the rocks occurring near the central parts of the Caledonian mountain chain. Previously these rocks have been regarded as pre-Cambrian porphyries (Carstens op. cit.).

The mineral assemblage of the augengneisses is microcline, albite, oligoclase, clinozoisite, quarts, biotite, hornblende, and some garnets. This paragenisis is stable at a rather low temperature, perhaps about 300° C, and it is probable that the porphyroblasts originated at this low temperature. The rocks are now found in epidote-amphibolite facies.

Experiments show that albite crystalizes out of water at a temperature of 200° C, when heated in a glass tube. The material necessary for the formation of albite is leached from the glass, thus rendering the solution strongly alcaline.

December 1941.

Universitetets mineralogiske institutt.

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Trykt 9 juni 1942.

NORSK GEOLOGISK FORENING

INNBYDELSE TIL ET LANDSMØTE I NORSK GEOLOGISK FORENING

Det har fra Bergen ved professor Niels Henrik Kolderup vært fremholdt at det vilde være ønskelig om foreningen kunde avholde enkelte større møter, eventuelt slå sammen to ordinære møter, for derved å gi de utenbys boende medlemmer anledning til å reise inn til Oslo for å overvære foreningens møter.

Styret er fullt ut enig i dette. Norsk geologisk forening er som navnet uttrykker ingen Oslo-forening. Foreningen er et forum for landets geologer, og foreningens viktigste opgave bør være å arbeide for en samlet innsats i den geologiske utforskingen av Norge.

Vi har i lengere tid vært inne på tanken om å avholde et årlig geologmøte med ledsagende ekskursjon. Vi mente, at møtet skulde strekke sig over flere dager og avholdes på forskjellige steder av landet hvert år. Det viser sig nu, at det er stor interesse for saken. Styret har derfor utarbeidet følgende foreløpige plan for et årlig landsmøte i Norsk geologisk forening.

I steden for to av de fire ordinære møter i vårsemesteret arrangeres, hvis forholdene tillater det, et landsmøte i forbindelse med en geologisk ekskursjon. Landsmøtet varer i flere dager og avholdes hvert år på forskjellige steder av landet. Der holdes foredrag om emner, som fortrinsvis er av generell interesse for fag-geologer. Gjennom diskusjoner vil de felles problemer bli belyst av et større antall av våre aktive geologer. Gjennom de årlige ekskursjoner vil medlemmene bli kjent med de geologiske forhold på forskjellige steder av landet. Landsmøtet vil innen vårt land ha de samme opgaver som de Nordiske geologmøter har for Skandinavia, og landsmøtene kan betraktes som en naturlig forberedelse til slike møter i Norge.

Avholdelsen av landsmøter vil kunne by på visse økonomiske vanskeligheter, men styret håper, at det i fremtiden skulde kunne skaffes tilveie et beløp til delvis eller hel dekning av reiseutgifter for fag-geologer, som ikke på annen måte kan få sine reiseutgifter godtgjort.

Styret har diskutert muligheten for å avholde et landsmøte våren 1941. Under de nuværende forhold kan det by på visse vanskeligheter å arrangere en ekskursjon, men på den annen side mener vi, at det iår er av spesiell betydning for geologene å kunne møtes og diskutere felles problemer. Styret har derfor funnet det riktig å avholde et landsmøte i Oslo i forbindelse med generalforsamlingen 11.—13. februar 1941. Tanken har vunnet tilslutning i Bergen og Trondheim, hvor flere av geologene har gitt tilsagn om å komme.

Der er ikke fastsatt noget endelig program for møtet, men vi har foreløpig tenkt at det skulde strekke sig over tre dager, slik at vi første aften hadde et åpningsmøte med foredrag, annen dag foredrag på Blindern (sannsynligvis et om formiddagen og et om eftermiddagen), tredje dag generalforsamling og avslutningsmøte med selskapelig samvær. Hovedtemaet for foredragene er: Geologiske undersøkelser og kartlegninger i fjellkjedestrøkene. Sannsynligvis vil der også bli holdt et eller flere foredrag om andre emner.

Program for møtet vil bli sendt ut i god tid.

Oslo 12. desember 1940.

Leif Størmer,
formann.

Trygve Strand,
sekretær.

LANDSMØTET 11.—13. FEBRUAR 1941

MØTE TIRSDAG 11. FEBRUAR KL. 18

Til stede 31 medlemmer og 15 gjester.

Formannen ønsket deltakerne velkommen og refererte hilsningsskrivelse fra Dansk geologisk Forening.

Innvalg.

229. Assistent, landbr.-kand. GUNNAR SEMB, Norges landbrukshøgskole, Ås.
Etter forslag av H. Rosendahl og T. Strand.

239. Konservator, ingeniør KRISTOFFER KRISTOFFERSEN, Geologisk museum, Oslo 45.
Etter forslag av I. Oftedal og L. Størmer.

231. Direktør WORM HIRSCH LUND, Jacob Fayes veg 2, Bygdøy.
232. Bergingeniør WORM LUND, A/S Sydvaranger, Kongens gate 5, Oslo.
Etter forslag av A. Rosenlund og H. Smith.

233. Cand. real. BRIT HOFSETH, Fagertunvegen 4, Bestun.
234. Mag. scient. IVAN T. ROSENQVIST, Vegdirektoratet, Schwensens gate 6, Oslo.
235. Bergingeniør ARTHUR O. POULSEN, Niels Henrik Abels veg 31, Blindern.
236. Stud. real. GUNNAR HENNINGSMOEN, Observatorie terrasse 56, Oslo.
237. Cand. real. ROBERT MAJOR, Kirkevegen 68, Oslo.
Etter forslag av T. Strand og L. Størmer.

Foredrag.

NIELS HENRIK KOLDERUP: **Trekk av Sunnhordlands geologi.**

I Sundhordland finner vi fire bygningsled:

1. Grunnfjellet i Folgefonnhalvøya og Skånevik.
2. De kambrisk-siluriske lagseriene.
3. Migmatittstrøkene i Haugarlandet.
4. Eruptivmassivet i Tysnes—Stord—Bømlo.

Grunnfjellsbergartene, migmatittene og eruptivmassivets bergarter står best mot nedbrytningen, og lager derfor det høgeste landet. De kambrisk-siluriske skifrene står mest langs med og i fjordene.

De viktigste verk om Sunnhordlands geologi er Reusch: Bømmeløen og Karmøen, Oslo 1888.

Grunnfjellet i Folgefonnhalvøya og Skånevik

kjenner vi dessuten fra undersøkelser av Thomassen, Rekstad og Odd Mortensen (upublisert).

I den vestlige delen er det eruptiver, granitter, granodioritter, gabbroer, olivingabbroer og serpentiner. Dessuten er det særlig i Skånevik en serie vulkanitter, både sure og basiske. Yngre diabasganger setter gjennom hele komplekset.

I den midtre delen finner vi gneiser, granittgneiser og eruptive breksier. Det er et migmatittområde.

Nordligst og østligst på Folgefonnhalvøya er det en del sedimenter, mest kvartsitter og konglomerater. Sammen med dem er det også lyse gneiser og amfibolitter.

Disse bergartene er rimeligvis Telemarkformasjonens vestligste utløpere i Sør-Norge. Struktur-retningene faller ikke sammen med de kaledonske. Og grensen mellom kambro-siluren og grunnfjellet viser tydelig diskordans de fleste stedene.

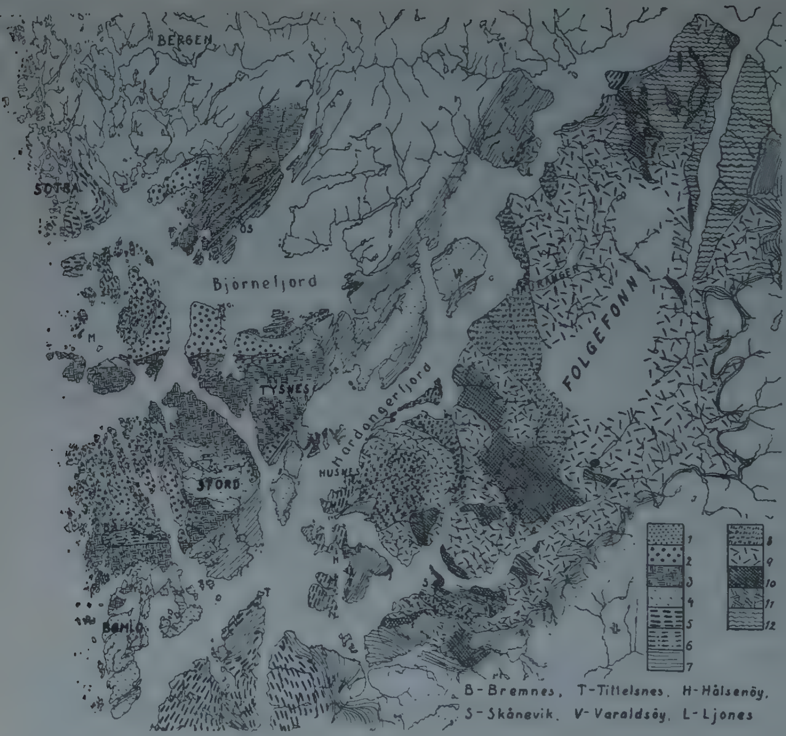
De kambrisk-siluriske lagseriene

er vel kjent fra Reusch's bok. Noe særlig nytt er ikke funnet siden. Det er alt overveiende glimmerskifre i forskjellige stadier. Det er dessuten en del kalkstein, og noen konglomerater, både grønt jaspiskonglomerat som svarer til Mobergkonglomerat og konglomerater av sure bergarter. Videre går adskillige vulkanitter, både sure og basiske, inn i lagseriene.

Skifrene er som regel svakt metamorfosert. Det fins nesten ikke granatskifre. Både Hardangerfjorden, Bjørnefjorden og det meste av Klosterfjorden er gravet ut i glimmerskifer.

Migmatittstrøkene i Haugarlandet

(som Reusch kalte Sveenhalvøen) er ganske sikkert et migmatittstrøk. Reusch's fine tegninger viser dette helt tydelig. Men det kan ikke være tvil om at det er et kaledonisk migmatittstrøk. Når en går fra glimmerskifrene, f. eks. nord på Tittelsnes, og sørover inn i gneisene, går en



1—7: Kaledon. 1. Trondheimitter. 2. Granitter. 3. Gabbroer. 4. Vulkanitter.
5. Migmatitter. 6. Injeksjonsmetamorfe skifre innen eruptivmassivet.
7. Kaledonske sedimenter, mest glimmerskifre. 8—12: Grunnfjell.
8. Granodioritter. 9. Granitter og gneiser. 10. Gabbroer.
11. Vulkanitter. 12. Sedimenter.
Målestokk: 1:1 000 000.

over gradvise overganger som skiller seg tydelig fra de skarpe formasjonsgrensene på Folgefonnhalvøya. En kan følge med hvorledes injeksjonene gjør seg mer og mer gjeldende, hvorledes bergartene etter hvert blir til finkornede gneiser, og videre til granittgneiser og grove eruptive breksier. Haugarlandet ligger helt skilt fra grunnfjellet lenger øst. Det er formodentlig det dypere partiet, som ligger mellom injeksjonsområdene i Stavanger-feltet i sør og Hålsnøy—Husnes i nord.

Eruptivmassiver i Tysnes—Stord—Bømlo,

„Øerne udenfor Hardangerfjordens munding“ som det heter på Reusch's kart, er satt sammen av to granittfelter, to gabbrofelter, et vulkanittfelt og to flak av kambrisk-siluriske bergarter som er metamorfosert av eruptivene. Det er et meget vesentlig trekk at det nordligste granittfeltet går kontinuerlig over i migmatittene lenger nord i Sotra og Øygaren, og at grensene mellom granittene og gabbroene overalt er uskarpe breksiegrenser, med granitten som det yngste.

Eruptivenes systematik.

Hvis vi forsøker å ordne eruptivbergartene i Sunnhordland inn i de tre kaledoniske stammene etter Goldschmidt, støter vi på store vansker.

En bredt anlagt sammenstilling av alle sikre kaledonske eruptiver i Sør-Norge, herunder også palingene eruptiver og vulkanitter, viser at det i all fall ikke er noen avgjørende hindring for å gruppere dem slik:

1. *De kaledonske intrusivers og effusivers stamme.* Til denne regner jeg både de grønne lavaers og intrusivers stamme og opdalitt-trondheimitt-stammen. Denne stammens bergarter ligger høgest i nivå, da mestedelen av bergartene er effusiver eller hypabyssiske intrusiver. De er også de yngste. En kan skille to grener i stammen, den natron-dominante og den kali-dominante.

2. *De store granittiske massivers stamme* er for en stor del palingene bergarter, hører i all fall til i stort dyp, og har sjelden effusive ekvivalenter som viser noen sammenheng i marken.

3. *Bergen—Jotunstammen* er også en abyssisk stamme, uten vulkanske bergarter. Den har to grener, en natron-dominant som vesentlig er de monomineralske anorthosittene, og en kali-dominant, som har jotunnoritter, mangeritter, mangerittsyenitter og bjerkreimitter. Perthittiske feltspater er typisk for denne grenen.

I ordskiftet etter foredraget deltok L. Størmer, V. Goldschmidt, A. Bugge og foredragsholderen.

V. M. GOLDSCHMIDT: I anledning den genetiske inndeling av de kaledoniske eruptivbergarter, som professor Kolderup hadde anført, kan det bemerkes at trondheimitt-bergartene har karakteristiske trekk, som tyder på et kun hypabyssisk nivå, nemlig den sterkt utpregede og ofte rekurrente sonarbygning av plagioklasene. En sammenfatning av en rekke eruptivbergarter, som regel tydelig kali-betonte bergarter, til en egen stamme fra meget dypt nivå, vilde omfatte stort sett de grupper av bergarter, som i 1916 blev sammenfattet under betegnelsen „bergarter av ennu ukjent stamme-samband", nemlig eruptivene fra Hitra og Smøla, øiegneisene omkring Trondheimsfeltets sparagmiter (inklusive tilhørende rapakivigranitter), en del av de mere kalirike granittiske bergarter i Stavangerfeltet, og de framskjøvne plater av sure eruptiver i høgfjellet. Tydningen av disse framskjøvne bergarters alder kunde da løses på en måte, som forener begge de eldre standpunkter, nemlig som rejuvenerte, framskjøvne grunnfjellsbergarter. Særlig interessant er Kolderups resultater om migmatitter og injeksjonsbergarter på Haugesundshalvøya. De sydlige utløpere av dette område er på Stavangerkartet av 1920 tydet som grunnfjell, men observasjonene kan meget vel forenes med Kolderups tydning og denne gir et langt bedre tektonisk helhetsbillede ved at den store foldningsgrøft fortsetter sydover i Haugesundshalvøyas injeksjons-sone Det ligger da nær å anta, at også det formentlige grunnfjell vest for Stavanger, i Tananger, kunde tilhøre samme injeksjons-sone, likeledes en del bergarter på Jæren. Kalksteinsdraget ved Klep på Jæren, med tilgrensende grønne silikatbergarter kunde utmerket godt passe som en sydlig fortsettelse av Stavanger-feltets grønne bergarter med kalkstein. Det vilde være meget velkomment, om det fra Bergens museum kunde igangsettes inngående undersøkelser i disse sydligste områder av den kaledoniske fjellkjede i Norge.

TOM. F. W. BARTH: **Litt om Sørlandets anorthositer.**

I mange år har jeg samlet materiale fra det store anorthositområde ved Egersund for om mulig å komme under vær med den egentlige mekanisme ved anorthositenes opståen. Man har jo alltid gått ut fra, at de var eruptive bergarter; og da er vi straks ved spørsmålet om hvordan det tilsvarende magma var sammensatt. Allerede dette er et problem som ikke er lett å løse. En anorthosit består jo nesten utelukkende av plagioklas; det er en monomineralsk bergart, og da smeltepunktet for plagioklas ligger høgt, måtte et magna av samme sammensetning også ha et høgt smeltepunkt. For å få temperaturen av anorthositmagmaet trykket ned til en verdi, som kan stemme med andre geologiske iakttakelser, er det derfor nødvendig å postulere en tilblanding av store mengder vann eller andre flyktige bestanddeler.

Så er det en ting til: anorthosit-feltspaten i Sør-Norge er en andesin med 40—45 An, men den er ikke i likevekt med en smelte av samme sammensetning. Tvertimot, smelten i likevekt med denne plagioklas vilde holde bare 10 An. Det er således en meget Na-rik smelte, som vilde svare til det restmagma, som blev igjen efter at anorthositen var krystallisert ut.

Imidlertid optrer anorthositene aldri alene. Fra alle kjente forekomster viser det seg, at de er geografisk associert med bergarter av syenitisk, mozonitisk, eller granodioritisk sammensetning. Det har da videre vært antatt, at disse alkali-rikere bergarter er genetisk beslektet med anorthositene, og at de representerer derivater fra et felles stammagma.

Det eneste anorthositområde som har vært skikkelig undersøkt er imidlertid den meget store bergartsprovins i Adirondacks. Robert Balks (1) undersøkelser her er meget fullstendige og verdifulle og har ført til en plausibel forklaring på de petrogenetiske forhold: Et oprinnelig dioritisk magma beveget sig opover i jordskorpen. I likevekt med dette magma, og suspendert i det, var store mengder av plagioklaskrystaller og mindre mengder av mørke mineraler. Gjennom meget lange tidsrom utskiltes derved fra magmaet 3 forskjellige bergartstyper: gabbro, anorthosit, syenit. Gabbro og anorthosit kan derved forklares som krystaldifferentiater (akkumulasjoner av faste mineraler), mens syeniten må betraktes som moderluten eller rest-magmaet.

Det er mange iakttakelser som viser, at denne antakelse er riktig, men jeg kan ikke gå nærmere inn på dem her. Jeg vil bare nevne, at efter at jeg hadde studert Adirondacks-området og personlig var blitt overbevist om det korrekte i Balks forklaring, mente jeg selvfølgelig, at noe lignende måtte gjelde for anorthositområdet ved Egersund.

Men det er dessverre ikke så enkelt.

Jeg skal nevne en del ting som ikke stemmer med en slik antakelse:

(1) Forholdet mellem anorthosit og omgivende bergart.

Omkring hele anorthositområdet ligger der bergarter av granodioritisk type. Disse granodioriter kunde altså tenkes å representere en slags moderlut eller et rest-magma, hvorfra anorthositene krystalliserte sammen med de beslektede noriter og gabbroer. Men i motsetning til forholdet i Adirondacks er det på Sørlandet intet, som direkte tyder på noe slektskap mellem anorthosit og omgivende granodiorit. I Adirondacks kan en se hvordan enkelte plagioklas-krystaller har skilt seg ut fra hovedanorthositen og er ført langt utover i syeniten — overganger mellem anorthosit og syenit finnes også. Dette er helt anderledes i Syd-Norge; her er alltid en konform grense mellom anorthosit og granodiorit, men grensen selv er helt skarp, knivskarp, og aldri finnes der anorthositplagioklas inne i granodioriten. Hvis granodioriten hadde vært moderlut til anorthositen, skulde det jo være rart om ikke en eller annen av anorthositens krystaller hadde blitt igjen.

(2) De veldige dimensjoner av enkelte av anorthositens krystaller.

Anorthositen er ofte svært grovkrystallinsk, nevestore og hodestore krystaller er ikke sjeldne — på ett sted, hvor bergarten var særlig grov, har jeg iakttatt krystaller på 110 cm lengde. Karakteristisk for disse krystaller er, at de er temmelig homogene — zonarbygning finnes meget svakt utviklet. Man kan tenke sig hvad det vil si, at en plagioklas på over en meters lengde ikke viser zonarstruktur — det betyr at mineralene må ha krystallisert ut av smelten overordentlig langsomt; under nesten isothermiske betingelser må de i overordentlig lange tidsrom, uten bevegelser, ha vært i kontakt med den granodioritiske smelte — og så plutselig må krystaller og smelte være blitt skilt fra hinannen så effektivt, at det ikke blev en krystall igjen i restsmelten og ikke så meget som noen dråper av restsmelten igjen blandt de utskilte krystaller.

(3) Udeformerte porfyriske krystaller i en skifrig grunnmasse.

Anorthositen har på svært mange steder en utpreget foliasjon, somme steder er den skifrig, somme steder sogar rent mylonitisk. Porfyrkrystaller som ikke er mekanisk deformert har jeg funnet i en sterkt presset, mørk anorthosit. Porfyrkrystallene er da vakkert utformede, blåaktige eller hvite andesiner, som ligger i en grunnmasse av helt gneisliknende karakter. Det ser derfor her ut, som om disse store andesinkrystallene ikke er egentlige porfyrkrystaller (dannet ved tidlig utkrystallisasjon), for da måtte jo de i minst like høg grad som grunnmassen være deformert — de ser mere ut som porfyroblaster, altså metamorfe dannelser som vokste fram ved omkrystallisasjon av den gneisliknende grunnmasse.

(4) Foldninger i anorthositen.

Jeg har nevnt, at anorthositen på svært mange steder viser foliasjon — alltid er dette tilfelle i de perifere deler hvor foliasjonen helt lovmessig stryker parallelt med grensene. Men på noen steder midt inne i området viser foliasjonen foldningsstrukturer, og en slik fold kan være omgitt av en helt massiv bergart. Det er vanskelig å skjønne, hvordan dette kan foregå, hvis ikke bergarten på en eller annen måte har gjennomgått en omkrystallisasjon.

(5) Ganger av anorthosit i anorthosit.

Ganger av anorthosit er ifølge litteraturen praktisk talt ukjente. Det er blitt satt i forbindelse med at et „anorthosit-magma" ikke skulde finnes. Det er derfor av meget stor interesse, at ganger av anorthosit på Sørlandet slett ikke er så sjeldne. Slike ganger blev først iakttatt av C. F. Kolderup (2), de er ikke av granodioritisk sammensetning, men er ekte anorthositiske; de består nesten bare av plagioklas, men plagioklasen er noe surere enn den som finnes i anorthositmassivene. Slik som de optrer i feltet skulde man tro at disse ganger måtte representere det restmagma som anorthositen kom fra. Rent kjemisk sett synes dette også rimelig. Men da skulde altså ikke granodioritene omkring ha noe å gjøre med anorthositene.

(6) Kjemi.

En bearbeidelse av kjemiske analyser av anorthositer med tilhørende ganger, noriter og gabbroer på den ene siden, og omliggende granodioritiske bergarter på den annen side, synes ikke å tyde på noe særlig slektskap dem imellom. Anorthositene med tilhørende bergarter ligger for seg selv, skilt fra alle de forskjellige granodioritiske bergarter.

(7) Ganger utenfor området.

Hvad jeg hittil har sagt om anorthositene, vanskeliggjør en genetisk forklaring. Det kunde nesten tyde på, at anorthositene var metamorfe og ikke eruptive. Ikke minst gåtefulle er anorthositgangene; for en gang kan man jo vanskelig tenke seg dannet på annen måte enn ved, at et magma blev intrudert i en sprekk — altså tvinges man herved til å anta eksistensen av et anorthositmagma. Og nu viser det seg, at der også på andre steder i Syd-Norge finnes gangliknende anorthositforekomster, som muligens kan kaste mere lys over dannelsesprocessen.

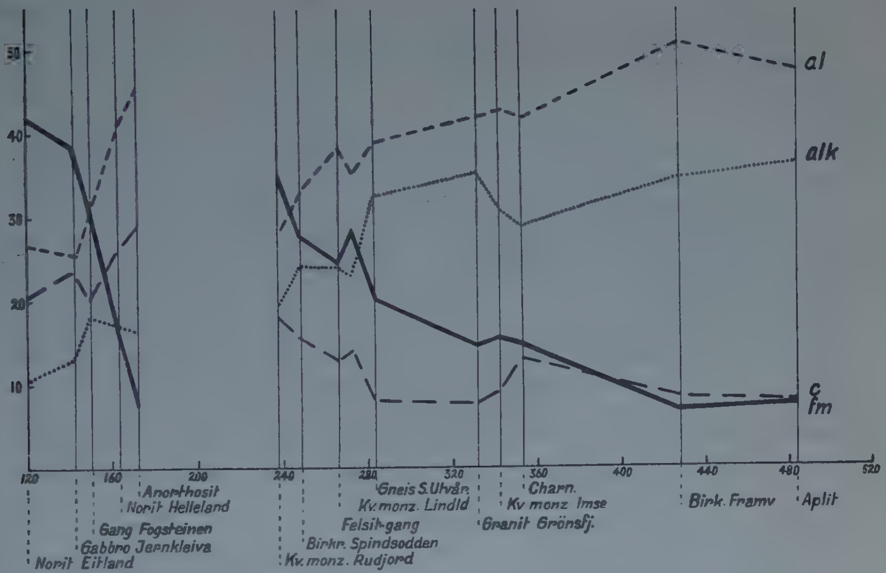


Fig. 1. Variasjonsdiagram for anorthositer og omgivende bergarter. Niggli-verdiene *al*, *fm*, *c*, *alk* er avsatt langs ordinataksen, *si* langs abscisseaksen. Det er tydelig at anorthositene med tilhørende noriter, gabbroer og ganger danner en gruppe for seg til venstre i diagrammet, mens de surere, omgivende bergarter danner en annen gruppe til høire i diagrammet.

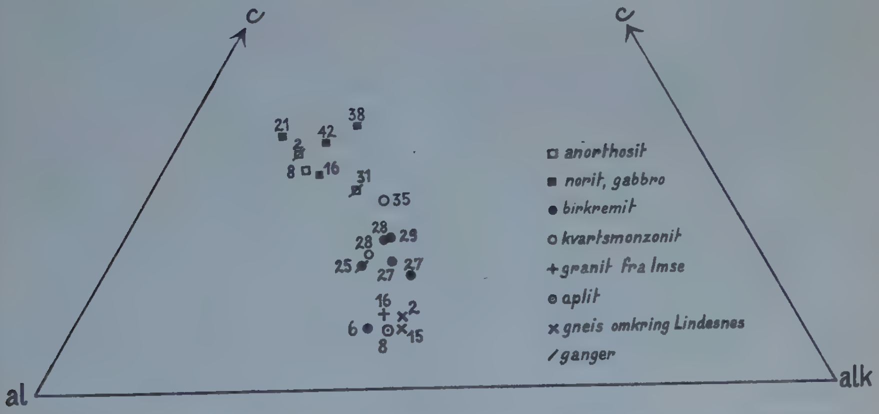


Fig. 2. Grafisk framstilling av analyseverdiene for anorthositer og omgivende bergarter. Projeksjonstrianglets hjørner representerer verdiene *al*, *c*, *alk*, tallene ved projeksjonspunktene angir den tilhørende *fm*-verdi.

På østsiden av de kaledonske eruptiver finnes der på enkelte steder irregulære masser av anorthosit som ofte er trukket ut til ganger som intruderer sidebergarten parallelt med skifrigheten, altså som lagerganger. En slik gang fra Fron har W. Werenskiold (3) beskrevet. Den består av labrador og hypersthen. Gangmidten er en meget pen og massiv bergart, men langsefter grensen er den meget skifrig, ofte mylonitisk, og krystallene er her dradd ut og er sterkt deformerte. I denne grensezonen ser bergarten ut som en snehvit takskifer. De mørke mineraler, som delvis optrer meget sparsomt, er mest hypersthen, men langs efter grensen er de forandret til klorit. Hele strukturen hos disse anorthositgangene viser at de må ha vært flytende under instrusjonen. Men temperaturen må ha vært lav, for noen kontaktvirkning på sidesteinen (som ofte er fyllit) kan ikke spores, frasett dannelsen av klorit. Vann er det eneste agens, som jeg kan tenke mig var istand til å trykke temperaturen av gangmagmaet til en så lav verdi, at det blir geologisk forståelig. Intrusjonsmekanismen synes derfor i dette tilfelle å kunne være slik som H. H. Hess (4) har antatt for enkelte dunit- eller serpentin-intrusjoner. For peridotit-intrusjoner har R. B. Sosman (5) kunnet påvise en intrusjonstemperatur på under 600°, men hvordan man skal forklare, at en bergart med peridotitens sammensetning kan intruderes ved så lav temperatur, er et problem, som må studeres ved laboratorie-eksperimenter.

Nærmere de centrale deler av den Kaledonske fjellkjede forekommer ganger og irregulære masser av en eiendommelig snehvit bergart som består av zoisit og albit. Prof. Holtedahl og jeg fant en slik gang ved Drivstuen, og stud. real. Hans Holtedahl fant et par slike forekomster lengere vest i Opdal. Kjemiske analyser av disse gangbergarter er, frasett det høgere vanninnhold, identiske med analyser av anorthosit, og de forekommer på samme måte som anorthositgangene f. eks. i Fron. Det er derfor rimelig å anta, at zoisitgangene representerer tidlig kaledonske eller pre-kaledonske ganger, som senere blev metamorfosert i grønskiferfacies under den kaledonske fjellkjedefoldnings tid. Det er neppe tvil om, at labrador under slike forhold vil omdannes til zoisit og albit.

Det store, uløste spørsmål er igjen, hvordan den oprinnelige anorthositgang kunde intruderes — for hvis den oprinnelige gangbergart krystalliserte ved lav temperatur fra et vandig magma, så burde man ventet zoisit dannet primært istedenfor labrador.

Jeg kan derfor bare slutte med å uttale, at anorthositganger, både friske og i omvandlet skikkelse, slett ikke er så sjeldne her i Norge — men hvordan man skal forklare deres dannelse, er for meg ennu en gåte.

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ANDERS KVALE: **Petrografisk-tektoniske undersøkelser i fjellkjeden mellom Bergens-buene og Voss.**

Det undersøkte område utgjør gradteig B 33 Aust, Bergsdalen, som ligger øst for gradteig Bergen. Her møtes Bergens-buene, foldningsgrøften og den sydlige del av den såkalte nordvesttavle, som tidligere blev ansett for grunnfjell.

Undersøkelsene faller i tre grupper: 1. petrografiske, 2. makrotektoniske (strukturundersøkelser i feltet efter Cloos' metode), 3. mikrotektoniske (undersøkelser over mineralkornenes orientering i orienterte tynnslip efter Sanders metode). Det tektoniske materiale fra de første tre års undersøkelser blev med stipendium fra Statens Forskningsfond av 1919 bearbeidet under veiledning av professor Ernst Cloos i Baltimore, U. S. A.

1. Petrografiske undersøkelser. I den største del av feltet faller bergartenes planstruktur mot SO. De dypeste nivåer finnes derfor i NV, de høgeste nær det SO hjørne. Bergartene kan regionalt og tektonisk inndeles i fire grupper:

a. I det dypeste nivå i NV er bergartene ensartede grå gneiser, typiske migmatitter. Sammensetningen er granittisk, til dels granodiorittisk.

b. Den neste gruppe ligger over migmatittene og under de kambroordovisiske glimmerskifre. Den består av omvandlede sedimenter og eruptiver. Sedimentene er vesentlig kvartsitt med litt kvartsskifer og konglomerat. Diagonallagning og bølgeslagsmerker er funnet. Av glimmerskifer finnes enkelte soner, de fleste er allochtone. Den optrer delvis i 1—10 m tykke striper, som til dels kan følges sammenhengende over flere mil. To slike striper går fra Vaksdal til Eksingedalen, hvor de forener sig med hovedsonen av glimmerskifre som kommer fra Sogn. Disse to striper danner skillet mellom migmatittene og bergartene over. De har fungert som skyvesoner for de store overskyvninger som har foregått i disse strøk.

Av eruptiver optrer både basiske og sure, både dagbergarter og dypbergarter. Dagbergartene er finkornige amfibolitter, omvandlede kvartsporfyritter og omvandlede kvartsporfyrer. De tilsvarende dypbergarter er saussurittgabbro, kvartsdioritt og granitt. De to første er eldre enn de tilsvarende dagbergarter og eldre enn kvartsittene, men er ikke funnet i kontakt med kvartsporfyren. Granitten er yngre enn alle de øvrige bergarter, men sender aldri ganger inn i glimmerskiferen.

c. Over denne gruppe ligger foldningsgrøftens glimmerskifre. En forholdsvis mektig sone kommer inn fra Vossetrakten i kartets NO hjørne, går mot SSV, senere V og NV og forsvinner i sjøen ved Vaksdal. Den blir smalere efter hvert. De siste 10—12 km er den slitt helt av og finnes bare stykkevis. Den dominerende bergart er kvarts-muskovitt-biotittskifer, sjelden med granat, undtakelsesvis med litt albitt eller oligoklas.

To andre felter med glimmerskifer og andre kaledoniske bergarter finnes i kartets SV og SO hjørne. I SV ligger Samnanger-feltet av ytre Bergensbue og i SO kommer inn det vi kan kalle Norheimsund-feltet, den nordligste del av Sunnhordlands kaledoniske sedimenter. De to felter har samme bergarter, nemlig glimmerskifer, grønskifer, polygent konglomerat, kvartsporfyr, trondheimitt, saussurittgabbro og serpentin, altså temmelig forskjellige fra den første glimmerskifersone.

d. Over de tre felter av kaledoniske glimmerskifre og andre bergarter kommer en gruppe bergarter som likner sterkt på den over migmatittene. Alle dennes bergartstyper gjenfinnes her, men gjennemgående mindre metamorfe. Denne fjerde gruppe svarer til høgfjellsetasjen i det centrale Norge og henger sammen med den omtrent uten avbrytelse. Den annen, gruppe som ligger over migmatittene, er en del av høgfjellsetasjen som er presset inn i glimmerskifrene og ikke over dem.

Aldersbestemmelsen byr på vanskeligheter. Glimmerskifrene med tilhørende effusiver og intrusiver er sikkert kaledoniske, overveiende ordoviciske. Migmatittene har fått fjellkjedens strukturretninger og må uten tvil være kaledoniske. I de to skyveflak av høgfjellsserien viser granittene sammenheng med migmatittenes granitter og er sikre kaledoniske. Det samme gjelder kvartsporfyrene. De andre bergarter er ulike de kaledoniske bergartene en kjenner fra Vestlandet og viser likhet med Telemark-formasjonen. Men diskordans mot kvartsporfyrene er kun funnet to steder, og den er ikke så sterk at den beviser en prekambrisk alder. Derfor er det mest sannsynlig at de er kaledoniske.[1]

I så fall må de opfattes som strand- og gruntvannsdannelser, en mellomting mellom fastlandseffusivene i det indre av Stord og glimmerskifrene med deres undersjøiske vulkanitter.

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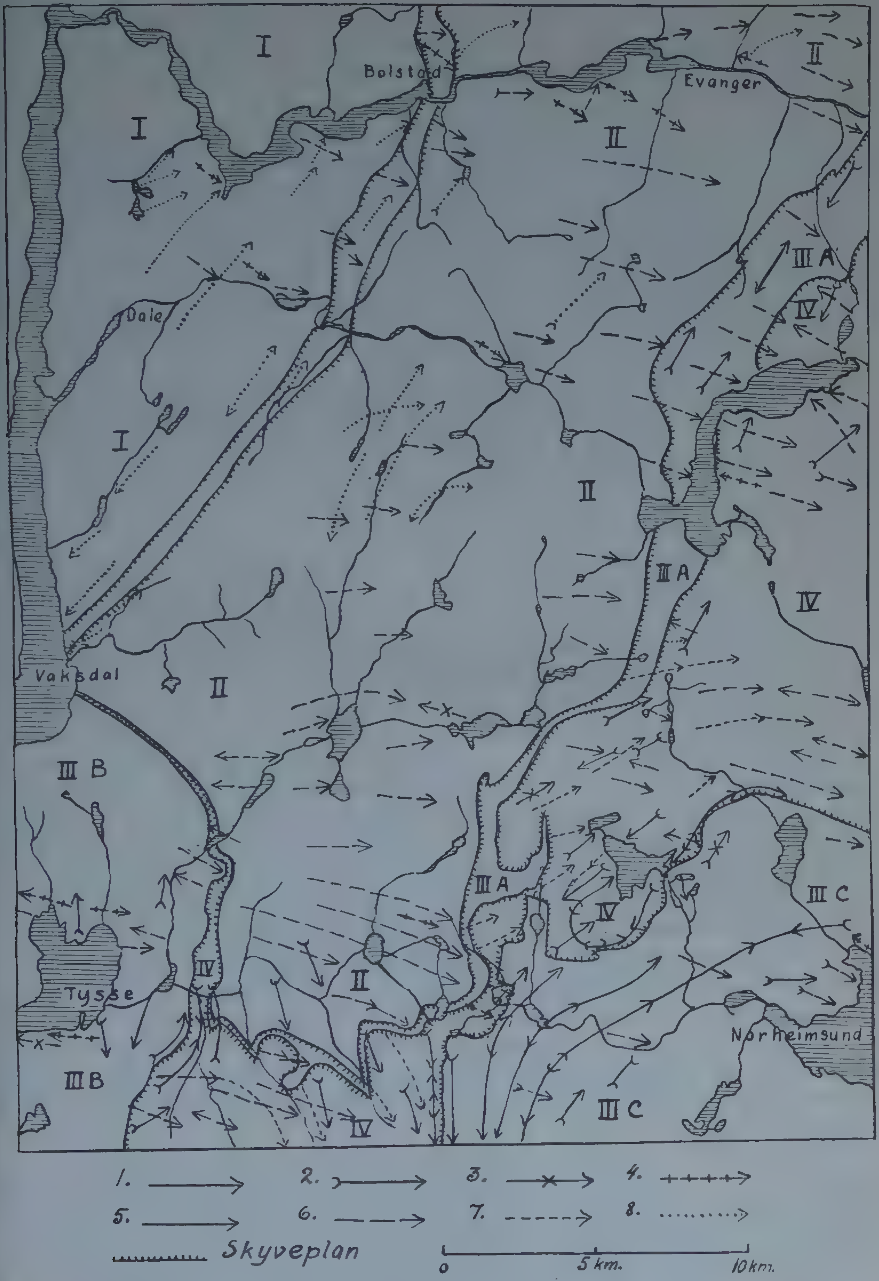
[1] Anm. januar 1942. Under feltarbeidet sommeren 1941 blev i det sikre grunnfjellsområde ved Eide i Hardanger funnet kvartsporfyritt og kvartsdioritt identiske med dem i skyveflakene. Dette gjør det overveiende sannsynlig, at skyveflakenes bergarter (undtatt granitt og kvartsporfyr) er prekambriske. Kvartsporfyrene må da opfattes som vesentlig intrusive.

Tegnforklaring til strukturkartet på omstående side.

I Migmatitter. II Undre skyveflak. III A Glimmerskifer mellem skyveflakene. III B Samnangerfeltet. III C Norheimsundfeltet. IV Øvre skyveflak

1. Strekning. 2. Foldningsakser. 3. Skjæringslinjer mellem skifrighet og kruskløiv. 4. Glidestriper. 5. Parallell skyvefronten. 6. Parallell skyveretningen. 7. Parallell avbøiet skyveretning. 8. Parallell fjellkjedens retning.

Pilespissene viser linjestrukturenes fallretning. Nr. 1—4 viser symbolene for de fire linjestrukturer når de er parallelle skyvefronten. Nr. 5—8 viser symbolene for strekning parallell de forskjellige retninger. Alle linjestrukturene 1—4 kan ha retningen 5—8. Symbolene blir da kombinasjoner av de to rekker.


I
I
I
Bolstad
Evanger
II
II
Dale
III A
IV
II
III A
IV
Vaksdal
II
III B
III A
IV
III C
IV
Tysse
II
III B
IV
III C
Norheimsund
1.
2.
3.
4.
5.
6.
7.
8.
Skyveplan
0
5 km.
10 km.

2. Makrotektoniske undersøkelser. De strukturelementer som har vært undersøkt kan inndeles i planstrukturer, linjestrukturer og sprekkesystemer. Vi skal se på dypbergartene (plutonene) for seg og de andre bergarter for seg, og begynner med de siste.

Planstrukturen i disse bergarter er alltid sekundær i den forstand at dens nuværende tilstand skyldes metamorfose. Men i alle bergarter undtatt glimmerskifrene følger den bergartens primære planstruktur praktisk talt overalt hvor det kan kontrolleres. I glimmerskifrene er lagningen som regel forsvunnet. Hvor den finnes er den enkelte steder parallell skifrigheten, andre steder blir den skåret av den. Sannsynligvis er skifrigheten parallell akseplanet for en foldning. Planstrukturen er stort sett parallell i alle bergarter over største delen av feltet, med fall mot SO og OSO.

En egen type av planstruktur, fracture cleavage, eller kruskløiv, som Reusch kalte den, er adskillig utbredt. I motsetning til skifrighetsflater har det i den ikke foregått nogen nydannelse av mineraler, men eksisterende mineraler, særlig glimmere, er til en viss grad bøiet inn i den. Overalt hvor det kan kontrolleres er kruskløiven i dette felt parallell akseplanet for en foldning.

Linjestrukturen kan deles i fire typer: strekning, foldningakser, skjæringslinjer mellem skifrighet og kruskløiv, og glidestriper. Strekning viser sig ved strekning av konglomerater, ved parallellordning av mineraler, eller ved stripning på skifrighetsflater uten at man kan se en parallellordning av mineraler. Også i kvartslinser kan en se slik stripning, hvis retning faller sammen med strekningen av bergarten omkring den. Kvartslinser kan vise en eldre strekningsretning efter at den er ødelagt i selve bergarten, og de har vært til stor hjelp i arbeidet med å bestemme utbredelse og relativ alder av de forskjellige strekningsretninger. Skjæringslinjene trer fram som små rifler på skifrighetsflaten, og er synlige selv om en ikke kan se den kruskløiv som svarer til dem. Glidestripene tilhører i regelen en senere fase av deformasjonen enn de andre linjestrukturene, og er derfor meget viktige for utforskningen av feltets deformasjonshistorie. En annen fordel er, at de viser den lokale bevegelsesretning.

Linjestrukturene er de viktigste for forståelsen av feltets tektonikk. På strukturkartet er de fire typer avsatt med forskjellige symboler (1—4). Nærliggende observasjoner er forbundet med linjer for å lette oversikten. Strukturkartet var til å begynne med temmelig broget. Men det lyktes å utskille fire grupper som er merket med forskjellige symboler (5—8). Først må dog nevnes litt om sammenhengen mellem linjestrukturen og bevegelsesretning.

På dette punkt er tektonikerne ikke enige. Sander, som har arbeidet mest med spørsmålet, hevder på grunnlag av erfaringer fra Alpene, at linjestrukturen som regel dannes loddrett bevegelsesretningen. Undtakelser er rent lokale, som f. eks. de fleste glidestripene. H. Cloos hevder at linjestrukturene også må kunne dannes parallelt bevegelsesretningen, og henviser til den kaledniske fjellkjede i Skandinavia. Her optrer ved siden av NO retningen en OSO retning, med strekning og foldningsakser parallelle retningen for de store overskyvninger. Th. Vogt har antatt at de er dannet under selve skyvingen parallelt dennes retning.

I det følgende skal vises at disse hypoteser ikke strekker til for å forklare linjestrukturene på gradteig Bergsdalen. Vi skal se litt nærmere på de fire grupper av linjestrukturer.

a. I kartets SO-del danner en skyvefront[1] grensen mellom høgfjellsetasjen og den underliggende glimmerskifer — grønskiferavdeling. Nær denne skyvefront er bergarten på begge sider intenst foldet med akser, skjæringslinjer og delvis strekning parallelt frontens lokale retning.

b. Hist og her sees en retning OSO, som er foldet efter akser parallelt skyvefronten og følgelig er eldre enn denne. NV-over fra skyvefronten blir retningen OSO sterkere og efter hvert enerådende. Rullestener med dimensjoner (100 × 3 × 1 cm) o. lign. viser at strekningen har vært meget intens. Denne strekning optrer i begge skyveflak og i glimmerskiferen mellom dem uten å forandre retning. Altså kan den ikke være eldre enn skyvingen. Forholdene ved skyvefronten viser at den er eldre enn foldingen med akser parallelle fronten. Den eneste mulige løsning blir at denne strekning er dannet under skyvingen parallelt dennes retning.

c. Den tredje gruppe optrer i høgfjellsetasjen i kartets SO-del. Her er høgfjellsetasjen et stykke meget smal, men blir bredere til begge sider. Den nevnte linjestruktur viser jevn avbøining fra OSO til henholdsvis S og ONO og blir tilnærmet parallell skyvefronten. Dette kan forklares slik: Hvor skyvedekket er minst og fronten ligger lengst tilbake, må skyvingen ha stanset først, mens den fortsatte på begge sider. Massene bak dette punkt blev fortsatt drevet framover, men blev tvunget til å forandre retning, inn i de tunger hvor bevegelsen fortsatte. En ny linjestruktur blev dannet parallelt disse avbøide skyveretninger. Disse retninger blir til dels parallelle skyvefronten, og da er det vanskelig å holde dem ut fra de retninger som er dannet langs denne. Et kriterium er det at den avbøide skyveretning framtrer vesentlig som strekking, mens det langs skyvefronten vesentlig har vært folding. Men selv om de to linjestrukturene enkelte steder kan falle sammen i retning, så viser forholdene andre steder at det virkelig er to strukturer med forskjellig oprinnelse.

Langs høgfjellsseriens grense mot Bergens-buene finner vi de samme forhold som langs SO-grensen: en eldre strekning omkring O til OSO, som er foldet med akselinjer parallelle grensen. Nærmest grensen følger foldningen den slavisk, lenger fra blir akselinjene jevnere og foldene svakere. Langs det meste av grensen faller høgfjellsserien inn under Bergensbuene. Det kan tyde på at efter at høgfjellsseriens bevegelse var stoppet op, blev buene presset mot den og delvis over den. Men da det ikke foreligger detaljerte strukturundersøkelser over Bergens-buene, blir dette nærmest en gjetning.

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[1] Skyveflak er en skjøvet bergartsmasse.
Skyveplan er en grenseflate for et skyveflak (i regelen ikke noen plan flate).
Skyvefront er forreste grense av et skyveflak, altså ikke hvilken som helst skjæringslinje mellom et skyveplan og jordoverflaten. Slike skjæringslinjer er på kartet kalt skyveplan. Av skyvefronter er det to på kartet, nemlig mot Norheimsundfeltet i SO og mot Samnangerfeltet i SV, hvor forholdet for øvrig kompliseres av Bergensbuene.

d. Migmatittene har meget god strekning med retning NO, altså parallell fjellkjedens hovedretning. De er adskillig foldet, med akser parallelle strekningen. Migmatittene har ikke vært skjøvet, men er presset sterkt sammen. Materialet er veket unda i retningen for minst motstand. Strekning og foldningsakser er dannet omtrent loddrett sammenpresningsretningen, som igjen er omtrent parallell bevegelsesretningen i skyveflakene.

Meget viktig er overgangen mellom migmatittenes retning NO og skyveretningen OSO. Den viser seg å være jevn. Dette kan ikke forklares hvis vi fastholder at linjestrukturer bare kan dannes parallelt en skyvefront eller parallelt eller loddrett en skyveretning. For å finne en løsning må vi prøve å bestemme bevegelsesretningen i bergartene. Her har vi to indikatorer. Den ene er linjestrukturen i stripene av glimmerskifer fra Vaksdal til Eksingedalen, de som har vært skyvesoner under skyvingen av det undre skyveflak. Disse linjestrukturer har alle retningen OSO, altså parallell den alminnelige skyveretningen. Den annen indikator er glidestripene. De har i alle bergarter over hele kartbladet hovedretningen OSO. Andre retninger optrer bare helt lokalt. Glidestripene viser at bevegelsesretningen i feltet efter at bergartene var så faste at det ikke kunde dannes strekning i dem, overalt var OSO. Derfor er det overveiende sannsynlig at hovedretningen for bevegelsen, også i den tid linjestrukturene blev dannet, var OSO. De bergarter som fikk sin struktur i grenseområdene mellom de sammenpressede og de skjøvne masser har altså fått linjestrukturer hvis retning jevnt forandret sig fra dypere til høgere nivå og dannet jevnt varierende vinkler med bevegelsesretningen.

Retningen OSO i de smale glimmerskifersoner tyder på at skyvingen langs dem foregikk efter at de skjøvne masser hadde fått sin struktur. Det er forhold i denne forbindelse som krever nærmere undersøkelse, men hovedsaken er at de viser den samme bevegelsesretning som ellers.

Dette at linjestrukturen kan danne jevnt varierende vinkler med bevegelsesretningen er analogt forholdet i plutoner. H. Cloos har vist at i dem representerer linjestrukturen den lokale retning for maksimum av forlengelse, og linjestrukturens vinkel med magmas bevegelsesretning kan variere fra 0° til 90°.

Denne analogi mellem strukturen i plutoner og i disse metamorfe bergarter, kan bety at det også var en viss analogi i den fysiske tilstand i disse bergarter og i en delvis størknet pluton. Det vil føre for vidt å komme nærmere inn på dette, men en undersøkelse av forholdet mellom deformasjon og krystallisasjon i disse bergarter vil forhåpentlig bringe klarhet i dette spørsmål.

Plutonenes strukturer må omtales ganske kort. Plutonene er konkordante, mer eller mindre linseformede masser. Deres planstruktur er over alt nær grensen parallell denne. Den er sterkest nær grensen og blir svakere mot midten. Den må være primær, dannet under størkningen. Deres linjestruktur er i regelen parallell de omgivende bergarters linjestruktur. Det viser at den blev dannet under innflytelse av de samme krefter som formet linjestrukturene i de omgivende bergarter. De må altså være dannet under skyvingen. Plutonene kan da ikke ha vært fullstendig størknet under skyvingen. På den annen side har de vært mer motstandsdyktige enn de omgivende bergarter. Disses planstrukturer er nemlig overalt parallelle plutonenes grenser, og i flere tilfelle er også deres linjestrukturer avbøiet nær grensene.

Om *sprekkesystemene* skal bare nevnes at tverrsprekker loddrett linjestrukturen er meget utbredt. De finnes overalt og har spillet en viktig rolle for utformingen av relieffet.

3. Mikrotektoniske undersøkelser. Foredragsholderen har utført over 50 Sander-diagrammer av mineralkornenes orientering i ca. 20 tynnslip. De viser mange interessante trekk, men har hittil ikke hatt den betydning for forståelsen av feltets historie som de makrotektoniske undersøkelser. Grunnen er delvis at Sanders skjema for tydning av diagrammene ikke passer. De fleste bergarter er av den type som Sander kaller B-tektonitter, med et tydelig symmetriplan loddrett den tektoniske B-akse, som faller sammen med den makrotektoniske strekning. Efter Sander skal bevegelsesretningen ligge i symmetriplanet loddrett B-aksen. Den klareste symmetri finnes i bergartene med sterk strekning mot OSO, og her viser at de makrotektoniske undersøkelser at strekningen er parallell bevegelsesretningen, mens de to retninger efter Sander skulde stå loddrett på hverandre. Dette viser tydelig, at en ikke som Sander kan trekke entydige slutninger om bevegelsesretningen bare på grunnlag av diagrammenes symmetri.

Et annet moment bør også nevnes. Det er almindelig antatt, at a-aksen i muskovitt stiller sig parallell bevegelsesretningen under deformasjon. Målinger i en av de sterkest strukne kvartsitter viser at muskovittenes a-akser er parallelle strekningen og således bekrefter resultatet av de makrotektoniske undersøkelser.

Når diagrammene er blitt gjennomarbeidet i lys av resultatene av de makrotektoniske undersøkelser, vil en utvilsomt få verdifullt materiale til klarleggelse av sammenhengen mellom bevegelsesretning og mineralkornenes orientering.

I ordskiftet etter foredraget deltok L. Størmer, V. Goldschmidt, Th. Vogt, T. Strand og foredragsholderen.

V. M. Goldschmidt: Det er meget gledelig, at de interessante bergarter og tektoniske forhold på gradteig-kartet Bergsdalen er så inngående undersøkt under anvendelse av de mest moderne metoder. Det vilde sikkert bringe verdifulle resultater, om undersøkelsene kunde bli utstrakt til områder lenger nord ved vestranden av foldningsgrøften. Spesielt mellem Fortun og Solvorn kunde man studere den diskordante overleiring av basalkonglomerat og alunskifer over sikre grunnfjellsbergarter i vestranden. Ved Solvorn overleires fylliten av skifrige grønne bergarter, som kanskje kunde svare enten til amfibolittene vestligst på kartbladet Bergsdalen, eller til de ordoviciske grønne bergarter. Meget interessant er også, på Sogndalsbladet, gangsystemene av tallrike smale trondheimitt-ganger, som er intrudert i tektonisk bestemte sprekkesystemer i labradorsteinmassene omkring Amble-bukten.

For mikrostudier over orienteringsforhold i pressede kvartskonglomerater vil Grønsennknipens konglomerat gi de beste betingelser, da man her har alle overganger fra upresset til meget sterkt deformert konglomerat i samme felt.

MØTE ONSDAG 12. FEBRUAR KL. 11^{15}.

Tilstede 33 medlemmer og 13 gjester.

Foredrag:

Steinar Foslie: **Geologien syd for Ofotenfjorden.**
Trykt i Norges geol. unders. nr. 149.

Thorolf Vogt: **Trekk av Narvik—Ofoten-traktens geologi.**

Foredraget var ledsaget av lysbilleder og geologiske karter i målestokk 1:50 000 over de strøk som blev omtalt, det var kartblad Narvik og den del av kartblad Ofoten som lå nord for Ofotenfjorden.

I Narvik—Ofotenfeltet har man en stor synklinal med fjellkjedesedimenter, svarende til min annen fjellkjedesynklinal av 1922. Tektonisk inntar Ofoten-synklinalen samme posisjon som f. eks. Trondheims-feltets hovedsynklinal lengre syd. I øst hviler fjellkjedesedimentene i Ofoten på et sikkert prekambrisk basalkompleks i Rombaks-vinduet i riksgrensetraktene øst for Narvik. I vest hviler de på Lødingen-granitten, som hører til „bunngranittene“. Vesentlige deler av „bunngranittene“ hører efter min mening til grunnfjellet, uten at jeg skal gå nærmere inn på dette her. Synklinalsedimentenes bredde er 40 til 50 km i de trakter, jeg har arbeidet I det hele er kartprofilets øst—vestlige lengde omkring 80 km. I foredraget blir det bare mulig å ta med enkelte trekk av geologien innenfor dette område.

Grunnfjellet i Rombaks-vinduet.

De eldste prekambriske bergarter er representert ved et suprakrustalkompleks, som overveiende består av temmelig ensformige brune finkrystallinske biotitt-kvarts-skifre. De kan delvis være rustne og noe kullstoff-førende, delvis kan de også bli så kvartsrike, at de kan kalles biotitt-kvartsitter. Spor av karbonatbergarter er også funnet. Denne sedimentserie inneholder på sine steder metamorfe lavaer av tilnærmet andesittisk karakter. Overalt er dette suprakrustalkompleks eldre enn de omgivende dyperuptiver. Det svarer åpenbart til de kvartsbiotitt-skifre, dolomitter m. v. som blev beskrevet fra Sjangeli-feltet, noe lengre syd, av Walfr. Peterson i 1897, til Kopparåsens (men ikke Vassijaures) arkeiske skifre, beskrevet av P. J. Holmquist fra traktene lenger mot øst i 1903, og også til Kjørrisfjells dolomitter m. v., omtalt av Foslie i 1922 fra traktene syd for Skjomen.

I alder kommer antakelig dernest en rekke finkornige gabbrobergarter etc., som optrer som større eller mindre inneslutninger i Rombaks-granitten og Hundals-syenitten i traktene nærmest riksgrensen.

Ennu yngre er Rombaks-granitten, som nærmest svarer til Vassijaure-granitten i Sverige, og som inntar det største areal i Rombaksvinduet så langt dette er undersøkt. Hundals-syenitten er bare skilt fra denne granitten ved en differentiasjonsgrense, med gradvise overganger. Begge bergarter er grå og grovkornige og særdeles rike på mikroklin; syenittene og kvartssyenittene skiller sig mest fra granittene ved avtakende kvartsmengde og tiltakende mengde av biotitt og hornblende. En får inntrykk av en differentiasjon ved gravitasjon innenfor en batolitt, med granitt i de øvre og syenitt i de dypereliggende deler. Ved noen delvis brede sedimentstriper er Rombaks-granitten delt i et østlig og et vestlig felt. I det østlige felt er den delvis noe vekslende og optrer her også sammen med Hundalssyenitten, mens den er mere ensartet i det vestlige felt, som omfatter Beisfjorden og den del av Skjomen, jeg har undersøkt. Den mere ensartede type i vest svarer til hovedtypen i øst.

Antakelig nær sammenhengende med Rombaks-granitten, men yngre enn denne, er Sildvik-granitten, en mere finkornig mikroklingranitt. Den optrer som vertikale eller steiltstående, delvis ganske brede injeksjoner i det østlige felt av Rombaks-granitt.

Det yngste ledd i grunnfjellet er efter alt å dømme en grovkornig biotitt-hornblende-gabbro, som optrer i et mindre felt ved Rombaksfjorden. Det har en utløper, som minner om en diabasporfyritt (se fig. 1).

Efter dette får en følgende aldersskjema for grunnfjellsbergartene i Rombaks-vinduet:

Dyperuptiver

5. Grovkornig biotitt-hornblende-gabbro (yngst)
4. Sildvik-granitt, finkornig mikroklingranitt
3. Rombaksgranitt og Hundals-syenitt, grovkornige og mikroklinrike bergarter.
2. Finkornige gabbrobergarter etc.

Suprakrustal-kompleks (Bottnisk alder)

1. Biotitt-kvarts-skifre etc. med andesittiske lavaer (eldst).

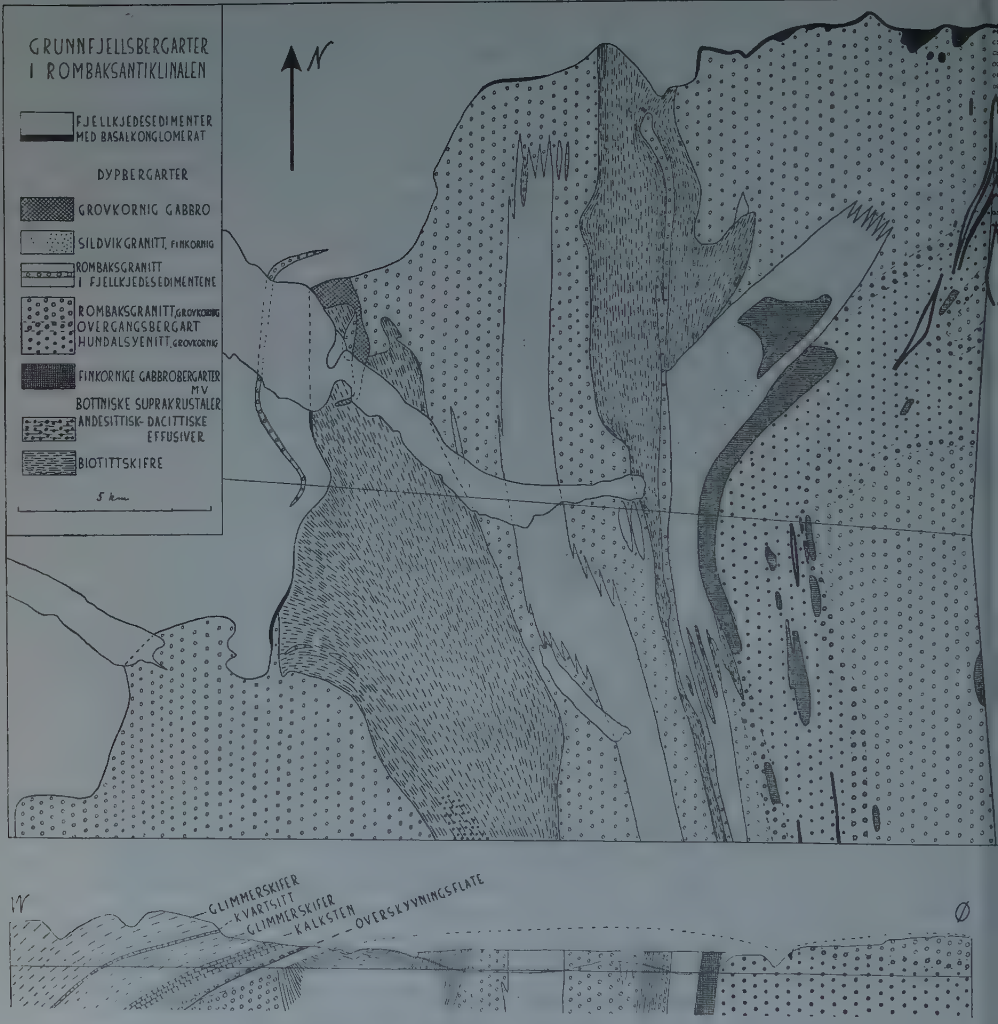
GRUNNFJELLSBERGARTER I ROMBAKSANTIKLINALEN
FJELLKJEDESEDIMENTER MED BASALKONGLOMERAT
DYPBERGARTER
GROVKORNIG GABBRO
SILDVIKGRANITT, FINKORNIG
ROMBAKSGRANITT I FJELLKJEDESEDIMENTENE
ROMBAKSGRANITT, GROVKORNIG
OVERGANGSBERGART
HUNDALSYENITT, GROVKORNIG
FINKORNIGE GABBROBERGARTER M V
BOTTNISKE SUPRAKRUSTALER
ANDESITTISK-DACITTISKE EFFUSIVER
BIOTITTSKIFRE
5 km
N
W
GLIMMERSKIFER
KVARTSITT
GLIMMERSKIFER
KALKSTEN
OVERSKYVNINGSFLATE
Ø

Fig. 1. Grunnfjellsbergarter i Rombaksantiklinalen øst for Narvik. Fjellkjedesedimentene er latt ubetegnet på kartet, undtatt basalkonglomeratet med basalkvartsitt (svart), mens de er tatt med på profilet. Eldst i grunnfjellet er det bottniske suprakrustalkompleks, biotittskifre og biotittkvartsitt, med tilnærmet andesittiske effusiver ved kartets sydrand. Dernest kommer finkornige gabbrobergarter m. v. (hørende til urgranittserien?), så den grovkornige mikroklinrike Rombaksgranitt med den nær sammenhørende Hundal-syenitt (antakelig svarende til Revsundsgranitten), og videre den finkornige mikroklinrike Sildvikgranitt (muligens svarende til Skellefte-granitten). Yngst er antakelig en grovkornig glimmerrik hornblendegabbro. I fjellkjedeskifrene optrer en overskjøvet plate av Rombaksgranitt med Sildvikgranitt.

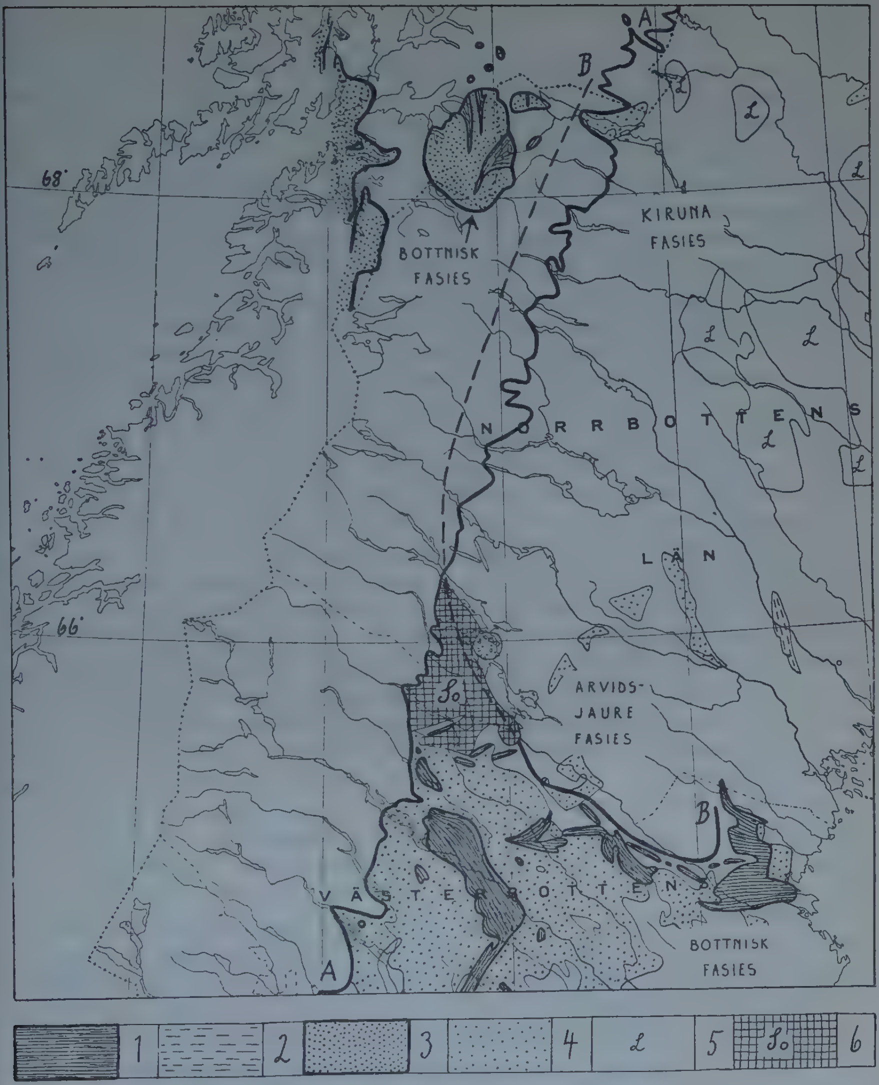

Fig. 2. Kart med trekk av fasiesutviklingen i de eldste prekambriske formasjoner i en del av Nord-Sverige og Nord-Norge.

1. Bottniske skifre. 2. Svartlå gråvakke.
3. a. Granitter m. v. i grunnfjellsvinduet øst for Ofotenfjorden. Antas å svare til Revsundsgranitt (Rombaksgranitt og Hundalsyenitt) og Skelleftegranitt (Sildvikgranitt). b. Bunngranitter (Tysfjordgranitt og Lødingengranitt m. v.) i formodete grunnfjellsvinduer lenger vest. Antas å være av samme alder.
4. Revsundsgranitt og Skelleftegranitt.
5. Linagranitt. 6. Sorselegranitt.

Vest og syd for linjen B—B: Bottnisk fasies.
Øst og nord for linjen B—B: Arvidsjaure-Kiruna fasies.
Linjen A—A representerer fjellkjedeformasjonenes østgrense.

Her, som i Nord-Sverige, representerer suprakrustalkomplekset det eldste ledd i fjellbygningen. Rett i øst inne i Sverige er imidlertid suprakrustalserien (Kiruna-porfyrene m. v.) helt annerledes opbygget. Vi må sydover til Skellefte-feltet, som nylig er så utmerket undersøkt av svenske geologer, for å finne tilsvarende formasjoner. Her faller det overordentlig naturlig å sammenføre vår serie med de bottniske skifre m. v. tilhørende den sydlige fasies i Skellefte-feltet. I 1937 påviste Alvar Högbom en særdeles interessant og viktig fasies-forandring i suprakrustalserien her. I syd har man underst leptitter sensu stricto (= den undre vulkanske serie), og herover en mektig serie med bottniske skifre. I overgangssonen har man underst de samme leptiter s. s., overleiret av bottniske skifre, som avtar i mektighet mot nord, og som inneholder benker av dacittiske og andesittiske lavaer; skiferserien overleires igjen av en porfyrittserie (= undre del av den øvre vulkanske serie). Ennu lenger mot nord, svarende til den nordlige fasieutvikling, er de bottniske skifre kilet helt ut; nedenfra regnet har man leptitter s. s., porfyrittserien, og herover den forholdsvis sure serie av Arvidsjaure-porfyrer (= øvre del av den øvre vulkanske serie), som er utredet av Erland Grip i 1935. Vår serie fra Rombaks-vinduet svarer meget smukt til den sydlige bottniske skifer, med sine innleiringer av lavaer i overgangssonen. Ofte er Skellefte-feltets skifre grafittrike, men der finnes også tilsvarende skifre som i Rombaken, og lavaene er svært like. Jeg har vist endel av bergartene til Alvar Högbom, som fant likheten slående, og litt har jeg også sett selv av forholdene i marken i Skellefte-feltet.

Videre faller det overordentlig naturlig å sammenføre vår Rombaks-granitt med den grovkornete Revsunds-granitten, som inntar så store arealer i de sydlige områder. Muligens kan våre eldste finkornete gabbrobergarter med gneiser etc. svare til urgranitt-serien, og vår mere finkornete Sildvik-granitt til Skellefte-granitten, men dette blir mere usikkert.

Et led i korrelasjonen tør også være forekomster av gullførende arsenkis i Rombaksvinduet, særlig ved Kjørrisfjell i Skjomen. Selv om forekomsten ved Kjørrisfjell neppe er særlig stor, er den allikevel blitt betegnet, av Foslie i 1922, som den mest lovende arsenforekomst i Norge. Den tør være knyttet til en granitt som svarer til Rombaks-granitten. I Skellefte-feltet har man som vel kjent malmforekomster med associasjonen gull-arsenkis, først og fremst ved Boliden, men også på andre steder. Tidligere var man tilbøielig til å anta, at malmbringeren i det vesentlige var urgranittene (Jørn-granitten); Sven Gavelin og Olof Ödman opfatter imidlertid Revsunds-granitten som malmbringeren, den siste forfatter bl. a. også for Bolidens vedkommende.

Når det gjelder Kiruna-suprakrustalene, paralleliserer Per Geijer en del av porfyrleptittformasjonen heroppe med effusivene i Arvidsjaures porfyrområde (= den øvre vulkanske serie), mens han finner liten likhet med det sydlige Skellefte-felts leptitter og skifre (hørende til den sydlige fasiesutvikling). En turde kunne sammenføre den opad stadig surere effusivserie ved Kiruna: Kiruna-grønsten, [Kurravaara-konglomerat], syenittporfyr og kvartsporfyr med tilsvarende led ved Arvidsjaure: Basaltisk andesit etc., [kvartsitter], andesitt, keratofyrer etc. og liparitt. Stort sett ser det ut til, at Arvidsjaure-fasies (= nordlig Skellefte-fasies) svarer til Kiruna-fasies. På den annen side har jeg pekt på ovenfor, at utviklingen i Rombaks-vinduet synes å svare til den sydlige Skellefte-fasies, med sin skiferutvikling. Et steds mellem Rombaks-vinduet og Kiruna-feltet måtte en da ha en tilsvarende fasiesovergang som i Skellefte-feltet. Det var mest rimelig, at fasiesovergangen var dekket av fjellkjedeformasjonene i den første (østligste) fjellkjedesynklinal. Disse forhold blev demonstrert på et kart, hvorpå fasiesgrensen var markert (se fig. 2).

Kaledonisk tektonikk i grunnfjellsvinduet.

Over det prekambriske kompleks i Rombaks-vinduet kommer et basalkonglomerat, mest bestående av små kvartsrullestener, ofte også med benker av kvartsitt. Basalkonglomeratet er delvis meget godt bevart, særlig i innfoldete fliker av fjellkjedeskifre i traktene omkring Bjørnfjell. Basalkonglomeratet finnes som et sammenhengende lag lengst mot øst, men taper seg snart, når en kommer vestover, hvor det bare er iakttatt på enkelte steder. De vestligste kjente lokaliteter ligger mellem Rombaken og Beisfjorden. Det antas at dets forsvinnen skyldtes tektonisk påvirkning.

I den undre del av fjellkjedesedimentene på begge sider av Rombaken optrer en plate av presset granitt, som er helt forskjellig fra de granittiske bergarter (trondheimitter), som ellers er så alminnelige i denne del av fjellkjeden, og som også forekommer i feltet heromkring, om enn først noe lenger mot vest. Granittplatens bergarter har derimot den største likhet med Rombaks-vinduets grunnfjellsbergarter. Det meste er såvel for øiet som under mikroskopet helt likt den grovkornige Rombaks-granitt, men også den mere finkornige Sildvik-granitt var representert. Foredragsholderen kunde ikke anta annet enn at denne granittplate representerte et parti av det prekambriske basalkompleks, som var kommet inn i fjellsedimentene ved en overskyvning.

I de østlige trakter hadde man som nevnt skarpt innfoldete partier av fjellkjedeformasjonene inn i grunnfjellet. Særlig klare var forholdene i området omkring Bjørnfjell og nordover. Disse synklinaler var invertert mot vest; de underliggende granitter etc. var sterkt forskifret særlig på synklinalenes østside. Det kunde nevnes at man hadde to helt forskjellige slags biotittskifre f. eks. i Bjørnfjellstrakten, nemlig biotittskifre hørende til de prekambriske skifre av bottnisk alder, og kaledoniske biotittskifre i den underste del av fjellkjedesedimentenes lagrekke. Men nettop ved Bjørnfjell var forholdene særlig klare på grunn av basalkonglomeratets optreden.

Foredragsholderen antok, at også det store forskyvningsplan, som måtte ligge nær over basalkonglomeratet, var foldet med i de innfoldete

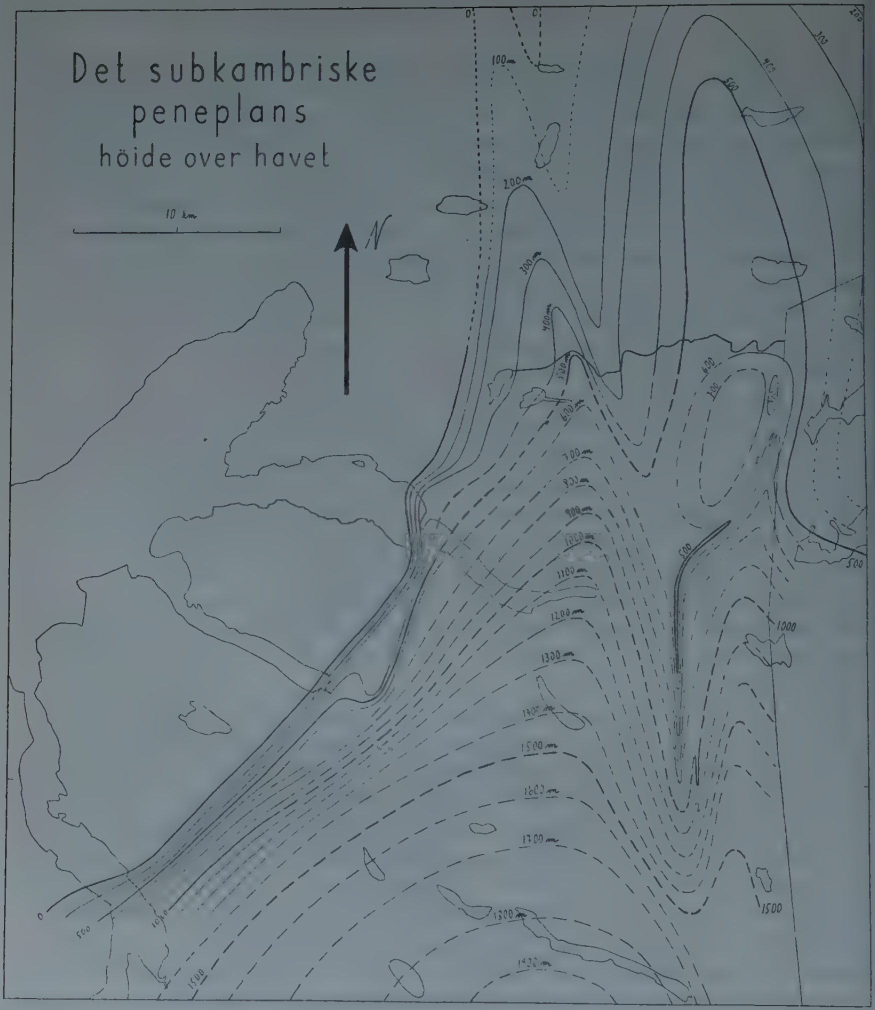

Fig. 3. Isobaser for det subkambriske peneplan i Rombaksantiklinalen øst for Narvik. Kartet omfatter kartblad Narvik med den nordligste del av kartblad Skjomen. Hvor en har et utgående av peneplanet, eller hvor dette er dekket av kambro-siluriske sedimenter, er linjene trukket opp helt (uten lengst mot nordvest). Hvor grunnfjellet ikke er dekket av yngre sedimenter, angir de brutte linjer peneplanets minimalhøide etter høiden av fjelltoppene.

I den nordlige del av området, hvor peneplanet i det vesentlige er dekket av fjellkjedesedimenter, stikker det opp små vinduer av grunnfjell, som viser at dette ligger flatt bølgende under et dekke av stort sett flattliggende fjellkjedesedimenter. Denne bygning fortsetter videre nordover, og er karakteristisk for store deler av det indre av Troms fylke („**Bardo-stilen**“).

På kartet legger en merke til to nord—syd-gående antiklinaler av annen orden, med en mellomliggende synklinal og en østlig synklinal, den siste på svensk side av Riksgrensen. I trakten ved Hundalen-Bjørnfjell (SO for midten av kartet, er de to annen ordens synklinaler forbundet ved en smal, skarpt innfoldet synklinal. Denne forbindelses-synklinal kan tenkes fremkommet ved de spenninger som opstår når grunnfjellspartiet i vest beveger seg i retning mot syd i forhold til grunnfjellspartiet i øst.

synklinaler. Dette førte til, at en måtte anta to forskjellige epoker under den kaledoniske fjellkjedefoldning. Først en stor horisontal forskyvning mot øst, delvis forbundet med overskyvninger. (M. h. t. forskyvningsretningen her og senere, refererer den sig til den rigide grunnfjellsplate øst for Torneträsk etc., som tenkes uten bevegelse. En annen sak er at denne faste plate i virkeligheten kan ha beveget seg vestover.) Etter at den store østlige forskyvning av fjellkjedeformasjonen har foregått, ser det ut til at det prekambriske underlag som helhet kommer med i bevegelsen. Trykket mot øst fra fjellkjedens centrale deler fortsetter, men nå er det underlaget selv som beveges. Herunder dannes antakelig grunnfjellsantiklinalen, og ihvertfall de skarpt innfoldete synklinaler. Disse viser, at underlaget er presset mot øst (foldene er invertert mot vest). Foldenes beliggenhet syntes videre å vise, at underlaget vestenfor de skarpe folder også hadde beveget seg litt i sydlig retning (når en antar at partiet i øst har ligget uten bevegelse). Et kotekart over det deformerte subkambriske peneplan innenfor den undersøkte del av Rombaks-vinduet blev demonstrert (se fig. 3).

Litt om fjellkjedesedimentene.

Innenfor de områder som behandles kan der stilles op følgende skjema for fjellkjedesedimentenes lagrekke:

Tabell I

Lagrekken nord for Ofotenfjorden.

Mektig glimmerskifer Butind kvartsitt Glimmerskifer	Niingen-serien
Bogen kalkstein Bogen jernmalm Glimmerskifer Laksåvatnets kalkstein Glimmerskifer Grønli kalkstein Grønli jernmalm, lokal Glimmerskifer Øvre Osmark kalkstein Glimmerskifer Osmark manganjernmalm Glimmerskifer Undre Osmark kalkstein Glimmerskifer Balteskar kvartsitt Glimmerskifer	Bogen-serien
Evenes kalksteiner med Leifset-marmor og dolomitt Evenskjær konglomerat	Evenes kalk

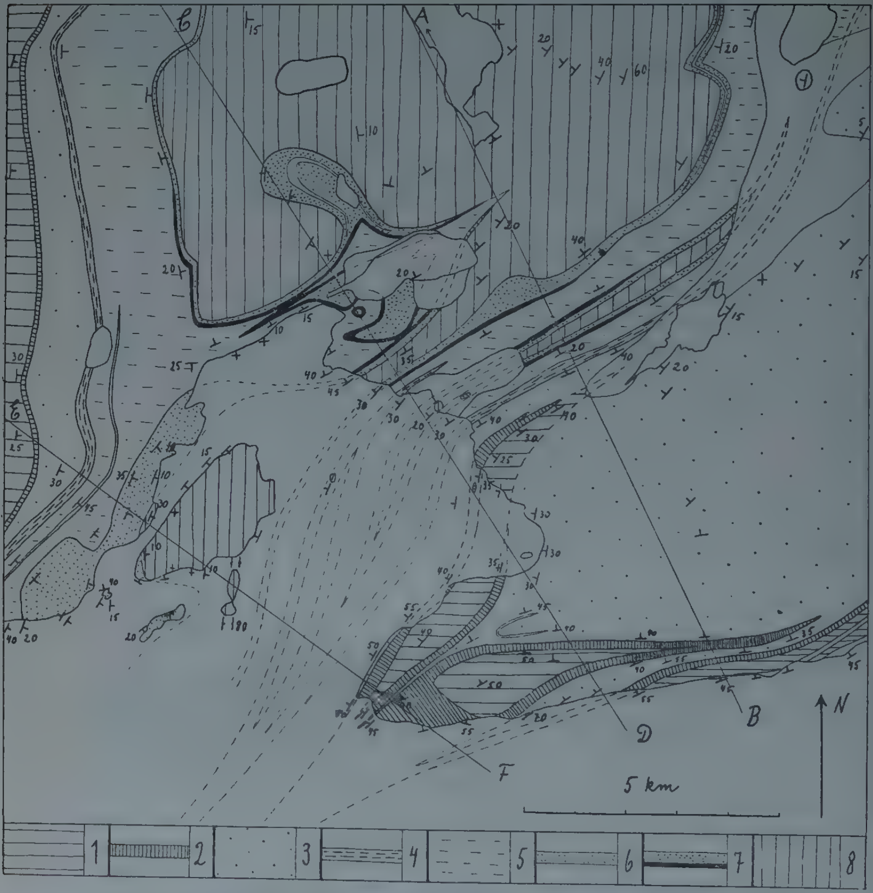

Fig. 4. Geologisk kart over traktene omkring Bogen i Ofoten.

8. Niingseriens glimmerskifre m. v. (øverst).
7. Bogenkalken underleiret av Bogen sedimentære jernmalm (svart på kartet, med punkter på profilene).
6. Bogenkalken uten kjent jernmalm.
5. Glimmerskifer, delvis med utkilende kalkstein.
4. Laksåvasskalken.
3. Glimmerskifer.
2. Grønlikalken.
1. Glimmerskifer (underst).

Profilene på fig. 5 er lagt etter linjene A—B, C—D og E—F.

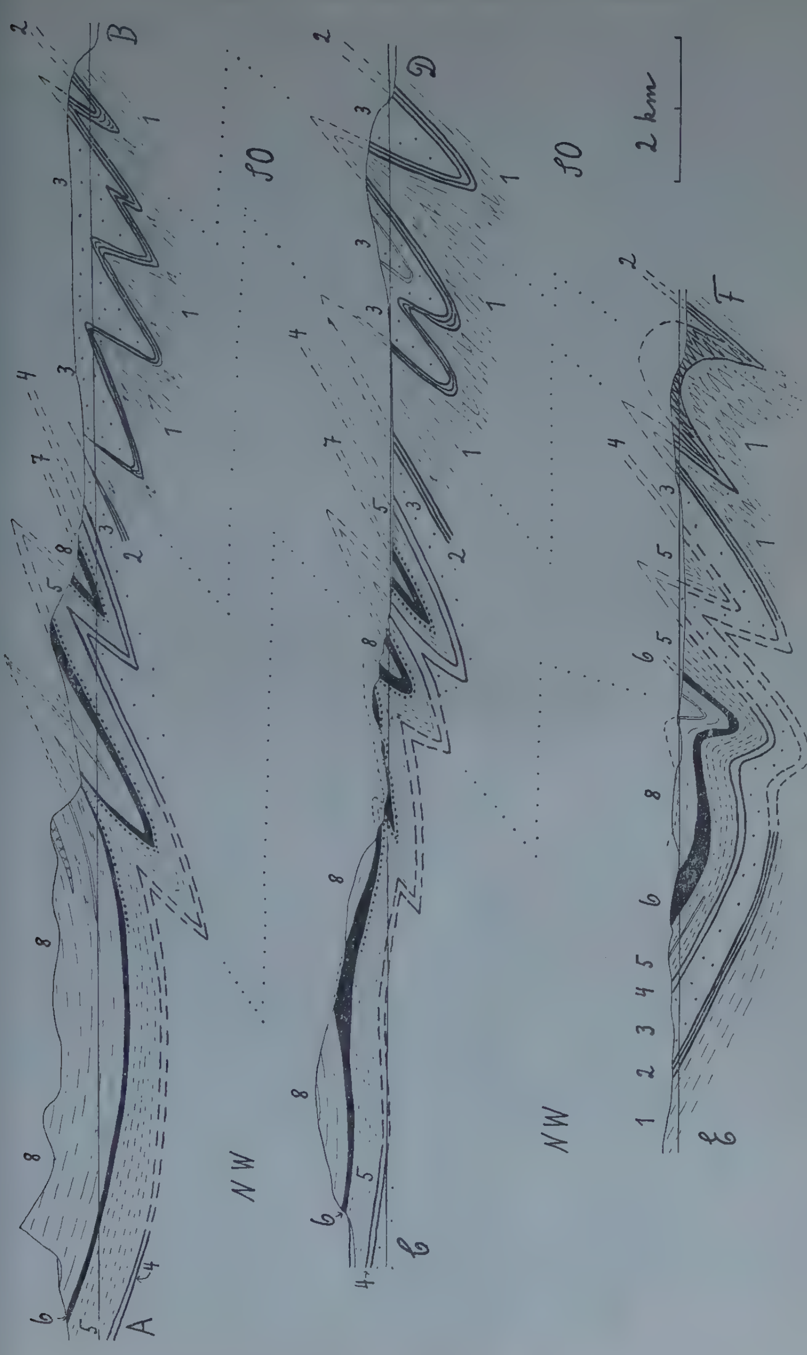

Fig. 5. Profiler fra traktene omkring Bogen i Ofoten.
Se fig. 4.

Glimmerskifer	Narvik-serien
Ballangen grafitt-skifer	
Glimmerskifer	
Narvik jernmalm	
Glimmerskifer	
Øyjord kalkstein	
Glimmerskifer	
Djupvik kvartsitt	
Glimmerskifer	
Rombaks-kalksteiner med skifrer	Rombaks-kalk
Glimmerskifre m. lokal kvartsitt	Rombaks-serien
Laveste dolomitter og kalksteiner i nordøst	
Fyllitt og glimmerskifer	
Basalkonglomerat og sandstein	
Prekambrisk underlag	

Det er imidlertid å merke, at en møter store fasiesforskyvninger fra område til område. En kan f. eks. se på Rombaks-kalksteinene. I nordøst, på den nordøstlige del av kartblad Narvik, var de tallrike og tilsammenlagt meget mektige, men avtok så gradvis i mektighet mot sydvest, til de ved Skjomen bare var representert av et ganske smalt kalklag. I vest, mot Lødingen-granitten, fantes ingen tilsvarende kalkstein i det hele tatt. De „laveste dolomitter og kalksteiner“ under Rombaks-kalken var i det hele tatt bare utviklet lengst mot nordøst. Evenes-kalkene var på den annen side mektigst i vest, og tok svært av mot øst, på Narvik-bladet. Balteskar-kvartsitten var kjent over hele området, men den vestlige gren tiltok svært i mektighet mot nord, mest nord for kartblad Ofoten (på kartblad Harstad). Ballangen grafitt-skifer og Narvik jernmalmnivå var kjent både i øst og i vest, nær Lødingen-granitten. Men hele den undre del av lagrekken (Rombaks-serien, Rombaks-kalken og Narvik-serien) var overordentlig sterkt redusert i vest. Dette kunde vel imidlertid også skyldes tektoniske forhold, men neppe disse alene.

En nærmere tektonisk analyse av det særdeles innviklede område omkring den nordre del av Tjeldsundet hadde vist at Evenskjær-konglomeratet måtte ligge under og ikke over Evenes-kalken, således som tidligere var antatt av forfatteren. Herved blir det også full overensstemmelse med lagrekken på Foslies Tysfjord-blad, hvor forholdene var enkle og klare.

Ellers blev foldningsteknikken mellem Veggfjell og Niingen, på den østlige del av kartblad Ofoten demonstrert. Man har her en serie svære isoklinale folder, med gjentakelse av lagrekken og inversjoner mot sydøst (se fig. 4 og 5).

Tjeldsundets cirkulære forkastning.

Til slutt blev en forkastning, som synes å tilhøre en svært lite kjent type demonstrert. Den egner sig imidlertid ikke til beskrivelse uten illustrasjoner, og derfor skal bare hovedsaken gjengis.

Det måtte være klart, at det gikk en svær forkastning langs den trange del av Tjeldsundet omkring Sandtorg—Evenskjær etc. Denne forkastning måtte enten være en horisontalforskyvning, eller den måtte ha en svær horisontal komponent, siden nemlig lagene står omtrent vertikalt på begge sider av forkastningen uten å passe sammen. Den horisontale forskyvning kunde bestemmes til 3,5 km på et sted; det var partiet på vestsiden av forkastningen som var blitt skjøvet nordover. Videre var det klart, at forkastningslinjen på kartet måtte være buet og ikke rettlinjet. Mot nord går den buede, delvis nordstrykende horisontalforkastning over i en mere øst—vestlig vertikalforkastning (eller forkastning med fremtredende vertikalkomponent). Her er partiet på nordsiden sunket inn.

Når det gjelder horisontalforskyvninger etter vertikale eller steiltstående flater, kan en lett overbevise seg om, at de mekanisk gunstigste flater er enten en plan flate (med en rett linje som skjæringslinje med horisontalplanet), eller en tilnærmet cylinderflate (med en cirkellinje som skjæring med horisontalplanet). Ved forskyvning langs andre flater vil der dannes større åpne rum, eller større sammenpresninger, etter at forskyvningene har foregått.

I det foreliggende tilfelle viser det seg at den buede forkastningslinje på kartet svarer meget nøie til en del av en cirkel med en radius på 13,5 km. Sektoren er omkring 90°. Ved modellforsøk kan en også vise forskjellige spesielle overensstemmelser, således den store vertikalkomponent hvor forkastningen går over fra å være cirkelformet til å bli mere rettlinjet. Videre viser det seg, at man får et ekstra stort press mot den konvekse del av bruddet. Her har dette utløst seg i kompliserte foldninger; det synes i det hele å være dette press som regulerer hele foldningstektonikken i denne del av området.

Årsaken til disse tektoniske forstyrrelser er åpenbart en svær granittmasse (Horvik-granitten), som er presset frem fra syd eller sydvest, inn i fjellkjedesedimentene. Foran den framskjøvne masse er sedimentene stuet sammen med vertikale lagstillinger. Men mot sedimentplaten i øst måtte man få et brudd, siden bevegelsen var for stor til at den kunde utløse seg bare som plastiske deformasjoner.

I ordskiftet etter foredraget deltok L. Størmer, N. H. Kolderup, C. Bugge, V. Goldschmidt, H. Rosendahl, O. Holtedahl og foredragsholderen.

V. M. Goldschmidt: En sikker løsning av de problemer som knytter sig til aldersbestemmelsen av eruptivbergartene, spesielt granittene, i Ofoten—Tysfjord-området vil man kunne få ved måling av radioaktive grunnstoffers omdannelsesgrad. Til bestemmelse av Tysfjord-granitten kunde man anvende uran—bly-forholdet, henholdsvis thorium—bly-forholdet i radioaktive mineraler fra Hundholmnes pegmatitt, særlig vil den av professor Vogt tidligere beskrevne friske (ikke metamikte) fergusonitt være utmerket skikket til en sådan aldersbestemmelse, og noen få milligram av dette mineral vil være tilstrekkelig for dette øiemed. Ellers vil man kunne benytte forholdet mellem rubidium og strontium ved atomvekt 87 til aldersbestemmelse, og her vilde man kunne benytte mineraler fra selve bergartene, nemlig biotitt og muskovitt, som erfaringsmessig er meget fattige på primært strontium. Også rubidiumrike pegmatittfeltspater vil være vel egnet for en sådan aldersbestemmelse. Der er truffet avtale om bygging av en masse-spektrograf for disse bestemmelser, leveringen fra utlandet er imidlertid utsatt på grunn av krigen. Man vil dog ved kvantitativ rubidium- og strontium-bestemmelse ved alminnelig spektrografi få maksimal-data for bergartenes alder, som vil kunne gi avgjørelsen mellom to geologiske alternativer.

THOROLF VOGT[1]: I anledning av Foslies forespørsel vilde han uttale, at han antok at de skarpe innfoldninger i grunnfjellsvinduet (Rombaksvinduet) øst for Narvik skyldtes en bevegelse i selve underlaget (grunnfjellet). Tenker en seg, at den store grunnfjellsplate inne i Sverige øst for Torneträsk har vært stasjonær og uten bevegelse (noe som ikke behøver å være tilfelle, den kan godt ha beveget seg mot vest) blir bevegelsen av grunnfjellsunderlaget i Rombaks-vinduet østlig. I de overliggende kambrosiluriske formasjoner vil dette yttre seg som en bevegelse mot vest, de skarpt innfoldete synklinaler er jo også invertert mot vest. En får derved to faser i fjellkjedebevegelsen, en første fase med den svære henimot horisontale forskyvning av de overliggende kambrosiluriske formasjoner mot øst, og en senere fase med en østlig bevegelse i selve grunnfjellsunderlaget.

Når det gjelder alderen av de vestlige granitter, som Lødingengranitten etc. er dette et ikke så helt enkelt problem. Kjemiske aldersbestemmelser vilde være på sin plass her. I Rombaks-vinduet øst for Narvik er forholdene klare og entydige, særlig da i den østlige del. Her har en en serie av granitter, kvartssyenitter og syenitter som overleires klart av de skjønneste basalkonglomerater, endog med forvitring ned i underlaget. Her er dyperuptivenes prekambriske alder utvilsom og utenfor enhver diskusjon. Kommer en til den vestlige del av Rombaksvinduet, til Beisfjord og Skjomen, har en de samme granitter (Rombaksgranitten) som lenger i øst, skilt fra dem ved et prekambrisk sedimentfelt. Selv om jeg i vest bare har sett basalkvartsitter og ikke basalkonglomerater, kan det etter min mening ikke godt være tvil om, at også disse granitter er prekambriske. Det er alt sammen identiske, eller henimot identiske granitter, som ligger i den samme geologiske posisjon innenfor et og samme antiklinalfelt (Rombaks-vinduet). Så dekkes Rombaks-granitten av kambrosiluriske sedimenter i en synklinal på bare omtrent 15 km's bredde, for å komme op i dagen igjen i vest som Tysfjord-granitt, på Foslies geologiske kartblad Tysfjord. Etter hvad jeg har sett av Tysfjord-granitten omkring Hundholmen feltspatbrudd og andre pegmatittganger, likner den overordentlig de sikre grunnfjellsgranitter lengre øst. Det er grå, sterkt kalibetonte granitter, delvis med hastingsitisk hornblende; holder en håndstykker op ved siden av hverandre, er de så like, at de knapt kan skilles. Jeg kan ikke komme fra, at det eneste naturlige er å opfatte også Tysfjord-granitten som prekambrisk. Derimot er den røde Lødingen-granitt lenger nord, hvor jeg har arbeidet, makroskopisk nokså forskjellig fra den ekte grå Tysfjord-granitt, selv om begge er utpreget kalibetonte. Jeg har også sett litt på forholdene langs kysten på sydsiden av Ofotenfjorden; granittene her likner svært på Lødingen-granitten, og alt taler for, at det er en og samme granitt som optrer både nord og syd for det brede fjordgapet. Av samme mening er Foslie også. Jeg har tenkt meg muligheten av, at denne røde eller rødlige granitt var skarpt skilt fra den grå Tysfjord-granitt, i områder hvor jeg ikke hadde vært. Etter Foslie går imidlertid de to granitter gradvis over i hinannen og er å anse som et eneste granittfelt, geologisk sett. Dette synes heller ikke urimelig, petrografisk er forskjellen ikke stor. En måtte i så fall utvide den prekambriske alder til å gjelde også for Lødingen-granitten. Her i vest kommer en imidlertid til det eiendommelige, at kontakten mot den overliggende kambrosiluriske sedimentserie er en injeksjonskontakt. Dette har Foslie funnet på sydsiden av Ofotenfjorden og jeg på nordsiden. På sine steder kan dog kontakten være sterkt tektonisk påvirket. På sydsiden, og forsåvidt også på nordsiden, har Foslie påvist, at det er en forholdsvis lite mektig lagerinjeksjon av mere finkornig granitt etc., beliggende stort sett over Tysfjord-granitten og under de kambrosiluriske sedimenter, som er av sikker kaledonisk alder. Foslie nevner også, at det er stor petrografisk likhet mellem den kaledoniske lagerinjeksjon og den underliggende Tysfjord-granitt (begge bergarter inneholder bl. a. flusspat). Herav trekker Foslie den slutning, at også Tysfjord-granitten er av kaledonisk alder, mens altså jeg er kommet til en prekambrisk alder for Tysfjord-granittens vedkommende, en opfatning som for øvrig Foslie også tidligere hadde. Her kommer det an på, hvad en skal legge mest vekt på. For meg står det som det eneste naturlige å føre Tysfjord-granitten sammen med de sikre østlige grunnfjellsgranitter, så like som disse bergarter er, og så kort vei som skiller dem ad. Etter min mening er dette det centrale trekk. På Foslies Tysfjord-kart har han også den lagerformete kaledoniske granittinjeksjon i kontakten over Skjomen-feltets granitt, som jeg ubetinget må opfatte som prekambrisk. Men hvorledes skal da den intrusive lagergranitt langs kontakten tydes? Det ser jo ut til at den henger sammen med underlagets granitt på en eller annen måte. På nordsiden av Ofotenfjorden er der ingen særlig høg metamorfosegrad langs Lødingen-granittens kontakt i vest. Jeg finner det derfor ikke særlig sannsynlig, at det har foregått en oppsmelting av de høgereliggende deler av grunnfjellsgranitten nær kontakten mot fjellkjedesedimentene. Derimot synes det rimelig å anta, at det kan ha foregått en differentiell oppsmelting av prekambrisk granittmateriale i dypere nivå, mer jo lengre vest en kommer. Poreløsningene kan være mobiliserte ved fjellkjede-stresset og den utpresste palingene magma intrudert østover langs kontakten mellom grunnfjellet og kambrosiluren. Dette vilde løse de vanskeligheter en møter med hensyn til „bundgranittene" i Ofoten-området.

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[1] Diskusjonsinnlegget er utvidet siden det blev svært kort tid til diskusjon etter foredraget (middagsmaten ventet).

Jeg vil imidlertid være forsiktig med å trekke for umiddelbare slutninger ut fra det ovenstående, når det gjelder Lofot-bergartenes alder. Lofot-bergartene med sine hyperstensyenitter osv. er petrologisk helt forskjellige fra alle de granitter og syenitter jeg har sett i Ofoten. De optrer nok innenfor bunngranittenes område, men de behøver ikke å være av prekambrisk alder av den grunn, selv om deres alder nok kunde taes op til revisjon. På sine steder inneholder de mengdevis av inneslutninger av marmor og skifre, deriblant også grafittskifre, og det er på det grunnlag min far og jeg for lang tid siden holdt dem for kaledoniske. En kan nok innvende at disse sedimenter kunde være av prekambrisk alder, og umulig er vel dette ikke. I Rombaks-vinduets grunnfjell har en jo prekambriske sedimenter, men riktignok av andre typer. Sedimentinneslutningene i Lofoten—Vesterålen er nærmest av kaledoniske typer. Videre kjenner jeg også helt upressede Lofot-syenitter som setter op gjennom sterkt pressede granitter av Ofoten-typen, noe som kunde peke i retning av kaledonisk alder. Alt tatt i betraktning synes jeg nok det er forskjellige ting, som peker i retning av, at Lofot-syenittene hører til kaledonidene, selv om en jo ikke kan avvise, at de kan høre til prekambrium.

På den annen side mener jeg, som framholdt alt i 1922,[1] at det kan være all grunn til å revidere all „bundgranitt" i den nordnorske fjellkjede ut fra disse synspunkter. Det tør være meget, som kan tale for, at mange, kanskje de fleste av disse granittfelter kan bestå av prekambriske granitter, delvis med kaledoniske, kanskje palingene granittinjeksjoner langs kontaktene. Spørsmålet om en eventuell tiltakende palingenese mot vest er også noe, en antakelig bør ta op til undersøkelse.

I anledning av Holtedahls bemerkning, kan jeg ikke si annet enn at den opfatning jeg har idag ikke er så svært forskjellig fra den jeg hevdet i et foredrag for mange år siden i denne forening.[2] Etter å ha omtalt „bundgranittene" i Nord-Norge, og at Foslie har antatt tilstedeværelse av en grunnfjellskjerne under den kaledoniske injeksjonsgranitt i områdene syd for Ofotenfjorden, skriver jeg: „Man må altså tenke seg, at

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[1] Thorolf Vogt: Bidrag til fjeldkjedens stratigrafi og tektonik. Geol. fören. förhandl. 44, 1922, s. 736.

[2] Trykt i Geol. fören. förhandl. l. c., se side 736.

Nordlands-synklinalen går op i luften over de uhyre brede granittfelter nord for Ofotenfjorden. Selv om granittkontakten mot sedimentene er en injeksjonskontakt, må man visstnok foreta en revisjon med henblikk på grunnfjellspartier i de mere centrale deler her.“ Noe liknende heter det også i et annet arbeide[1] fra samme tid, hvor det er tale om pegmatittgangen ved Hundholmen og Tysfjord-granitten: „Zwar liegt die Lokalität mitten in dem kaledonischen Faltungsgebirge, der Granit bildet aber hier einen Antiklinal, der zwischen meinen ersten und zweiten Hauptsynklinalen liegt. An dieser Stelle wurde dann die Unterlage des Faltungsgebirges von der Erosion erreicht, und der Granit ist wohl deshalb als ein Fenster aus älterem Gebirge aufzufassen. Es wäre insofern recht interessant, wenn sich der Hundholmen-Pegmatit als Grundgebirge auffassen ließe“ etc. Det kan også henvises til mitt geologiske oversiktskart over Nord-Norge, utgitt i 1924 av Norges geologiske undersøkelse, hvor det under fargeforklaringen står opført: „Fjellkjedens eruptivbergarter. Granitt (eventuelt med enkelte partier av grunnfjellsgranitt).“

Det er jo liknende synspunkter jeg framdeles hevder, jeg er bare blitt bestyrket i min oppfatning, etter hvad jeg har sett senere. Jeg skulde kanskje også være tilbøielig til å gå lenger på denne veg; således kan en ikke lenger være helt sikker på, at selv de granitter, som ligger oppe i den kambrosiluriske lagrekke, og hvis underside er blottet, alltid er av kaledonisk alder. I foredraget har jeg nevnt en smal granittplate i den undre del av kambrosiluren øst for Narvik, som jeg antar er av prekambrisk alder. Liknende overskjøvne partier tør kunne forekomme også lengre mot vest, det gjelder f. eks. muligens Horvik-granitten, som har frambragt cirkelforkastningen i Tjeldsund-trakten, uten at jeg kan gå nærmere inn på disse ting her.

Om aftenen var møtets deltakere innbudne til å overvære Geografisk selskaps møte med foredrag av direktør Th. Hesselberg og professor W. Werenskiold om „Klimaforandringer i Norge i vår tid“.

MØTE TORSDAG 13. FEBRUAR KL. 14

Til stede 32 medlemmer og 7 gjester. Til møtet var Bergingeniørforeningens medlemmer innbudne.

Foredrag:

C. W. Carstens: **„Om geokjemiske undersøkelser av malmer.“**

De elementer, som optrer i våre malmer, kan som bekjent inndeles i 1. de mineraldannende og i 2. de ikke mineraldannende elementer. Til den første type hører f. eks. Cu, Fe og Zn osv. Til den annen type hører f. eks. Co og Se i våre svovlkismalmer, V i våre jernmalmer, Cd i våre zinkmalmer osv.

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[1] Thorolf Vogt: Thalenit, Benedicks. Videnskabsselskabets Skrifter I. Mat.-Naturv. Kl. No. 1, 1922, se s. 22.

Bestemmelsen av de underordnede elementer i våre malmer, både de mineraldannende og de ikke mineraldannende, er imidlertid av meget stor interesse.

1. har flere av disser elementer ren praktisk økonomisk betydning, da de undertiden optrer i så store kvantiteter, at de kan nyttiggjøres. Jeg behøver bare å minne om Co i svovlkis og V i magnetitslig.

2. er disse elementer av stor genetisk betydning, idet elementfordelingen er forskjellig hos de forskjellige malmtyper. Vi kan si, at elementfordelingen er en funksjon av malmens genesis. Har vi først lært å kjenne elementfordelingen i forskjellige karakteristiske malmtyper av forskjellig genesis, vil vi altså ved å undersøke elementfordelingen av de underordnede elementer i en malm omvendt kunne slutte oss til malmens genesis, selv under forholdsvis kompliserte forhold. Og kjennskapet til malmens genesis er av stor betydning også for den praktiserende malmgeolog.

Utforskningen av lovene for elementfordelingen i de forskjellige bergarts- og malmtyper kaller vi som bekjent geokjemi. Og takket være professor Goldschmidt er Norge på geokjemiens område blitt et foregangsland. En rekke av hans arbeider er blitt av fremtredende betydning for studiet av våre malmers geokjemi.

Vi har i Trondheimsfeltet innenfor *Bymarkgruppens* grønstensområde 2 forskjellige kistyper: 1. vasskistypen = Leksdals-typen, representert av en mengde i økonomisk henseende verdiløse kislag av mektighet noen mm op til max. ca. ½ m, spredt omtrent over hele grønstensbenken, fra Røros-gruppen op til Hovin-gruppen, og 2. gangkistypen, representert bl. a. av Løkken hovedgrubes kisgang. I det følgende blir vesentlig kun disse 2 kistyper behandlet. Begge viser en forholdsvis svak metamorfosegrad og i kjemisk henseende i hovedtrekkene antakelig en primær karakter.

Vasskistypen er sedimentær, den har tett struktur og optrer i almindelighet i sterk veksellagring med svartfjell-lag, grafitskifer, jaspislag og grønstensskifer. Gangkistypen er hydrotermal. Den står i stedlig og genetisk forbindelse med gabbrobergarter. Den er som gabbrobergartene yngre enn grønstenen (og altså også yngre enn vasskislagene, som tilhører grønstensgruppens dannelsestid). Gangkisen gjennemskjærer således vasskisen på en flerhet av steder (se Fig. 1).

Gangkisen er i strukturell henseende hvad vi i almindelighet vil kalle tett. Korndiameteren ligger gjennemgående mellem 50 og 200 μ. Men sammenligner vi gangkisens struktur med vasskisens struktur, finner vi imidlertid en betydelig forskjell. Vasskisens korndiameter i Løkkenfeltet ligger således gjennemsnittlig kun omkring 5 μ (se Fig. 2).

I almindelighet er det ikke vanskelig å adskille disse 2 kistyper. Men undertiden er vasskisen i sterkt metamorfe strøk omkrystallisert slik, at den strukturelt minner om gangkis. I slike tilfeller er en adskillelse vanskelig, såvel makroskopisk som mikroskopisk. Er det nu mulig å adskille disse 2 kistyper kjemisk? Vi har lenge visst, at vasskisen er omtrent kobberfri, d. v. s. kobbergehalten er i vasskisen som regel under

0,1 %, undtakelsesvis går den op til 0,2 % eller deromkring. Og i almindelighet holder gangkisen ½ % kobber eller derover. Men der finnes også gangkis med kobbergehalt ned til 0,1 %, så kobbergehalten kan kun vanskelig benyttes som skillemiddel. Den eneste norske kisforekomst i drift, som tilhører vasskistypen, er Stord. Og en generalanalyse av Stordkisen viser 0,01 % kobber. Kobber inngår i våre kisforekomster alltid i form av kobberkis.

Vasskisen har som regel en ganske betydelig kullgehalt, i de fleste tilfeller op til 1,5 % og tildels derover. Men der finnes også vasskiser med helt ubetydelig kullgehalt, særlig de omvandlede vasskiser viser undertiden en kullgehalt = omtrent null. Så kull kan heller ikke benyttes som skillemiddel. Kull inngår i vasskisen som grafit (eller bitumen).

Selengehalten er derimot av betydelig interesse. Gangkisene holder således alltid en betydelig mengde selen, mens de sedimentære jernsulfidforekomster, ifølge Goldschmidt og Strock, er meget selenfattige, respektive selenfrie. På laboratoriet på Løkken er det derfor blitt utført en rekke selenanalyser, dels av gangkis, dels av vasskis. Den gjennemsnittlige selengehalt i kobberfattig gangkis i grønstensområdet er 20 til 30 g/t. Vasskisens selengehalt er derimot i almindelighet absolut 0. Undtakelsesvis vil selengehalten kunne anføres som spor, hvilket tilsvarer en selengehalt av 1 g/t eller mindre. Ved hjelp av selengehalten er det derfor alltid mulig å holde vasskis fra gangkis, hvilket er av meget stor betydning for den praktiserende malmgeolog.

De kobberrike gangkiser viser alltid betydelig høiere selengehalt enn de kobberfattige. Dette forhold fremgår meget tydelig av nedenforstående tabell.

	Cu i %	S i %	Se i g/t	S : Se
Svovlkiskonsentrat, Folldal	0,32	ca. 48	43	11 000 : 1
Kobberkiskonsentrat, »	16,26		182	
Svovlkiskonsentrat, Vigsnes	0,33	ca. 48	33	15 000 : 1
Kobberkiskonsentrat, »	21,26		104	
Svovlkiskonsentrat, Bjørkåsen	0,79	47,34	16	30 000 : 1
Kobberkiskonsentrat, »	18,12		93	
Svovlkiskonsentrat, Mofjellet	1,03	48,12	10	48 000 : 1
Kobberkiskonsentrat, »	23,23		30	
Kobberfattig kis, Løkken	0,28	ca. 30	7	42 000 : 1
Kobberfattig kis, »	0,75	ca. 30	18	17 000 : 1
Eksportkis, »	2,50	42,50	60	7 000 : 1
Kobberrik kis, »	3,83	ca. 46	90	5 000 : 1
Kobbermalm, »	6,08	ca. 46	120	3 800 : 1
Kobbermalm, rik, »	16,26	ca. 36	198	1 800 : 1

Fig. 3 viser kobber- og selengehaltene i 2 tverrslag i hovedgruben på Løkken. Prøvene er uttatt som gjennemsnittsprøver fra ligg til heng, hver prøve over en lengde av 5 til 10 meter. Vi ser, hvordan disse

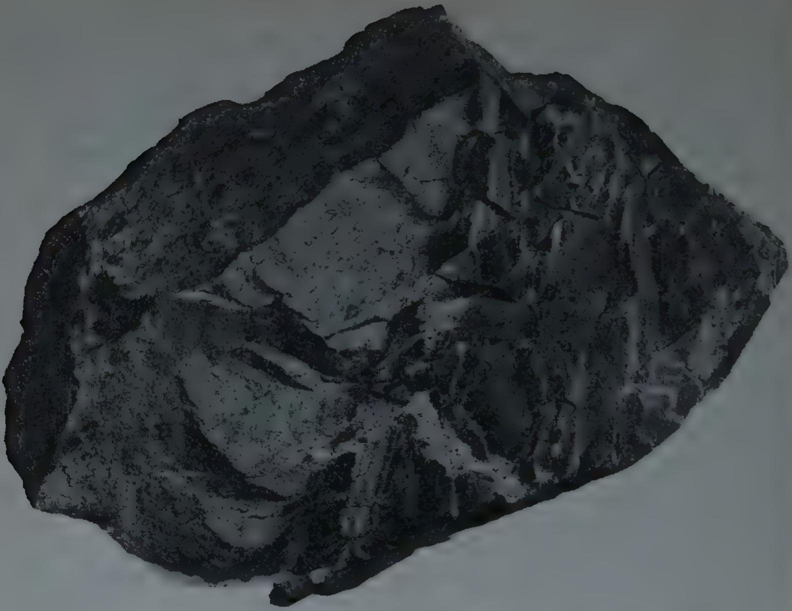

Fig. 1. 4/5 naturlig størrelse. Til venstre gangkis, til høire vasskis med årer av gangkis.

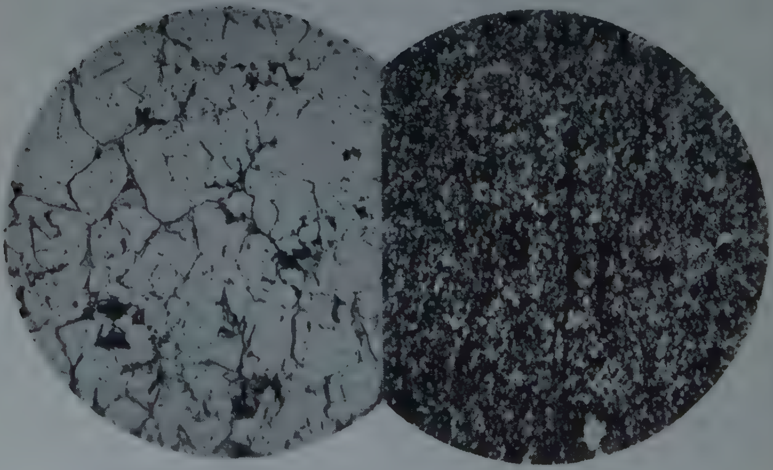

Fig. 2. Forstørrelse 80 ganger. Til venstre gangkis, til høire vasskis.

gehalter går påfallende proporsjonalt. Selengehaltens avhengighet av kobbergehalten er for de sedimentære sulfidforekomsters vedkommende også omtalt av Goldschmidt og Strock: „Zusammen mit Kupfer-Erzen werden demnach in sedimentären Sulfid-Lagerstätten größere Mengen von Selen, bezogen auf Schwefel, angereichert, als sonst in sedimentären Sulfiden“ (1).

Av en rekke selenanalyser av kobberfattige gangkiser fra Bymarkgruppen fremgår, at vektsforholdet S : Se i svovlkisen gjennemsnittlig ligger omkring 25 000 : 1. I svovlkis fra en pegmatitgang i Iveland er forholdet S : Se = 22 000 : 1 og i svovlkiskonsentrat fra Fosdalens jernmalmforekomst er forholdet 23 000 : 1. Dette forhold svarer temmelig nøiaktig til det forhold, som Goldschmidt og Strock har funnet i svovlkis fra Grass Valley, California, som er antatt å være dannet hydrotermalt ved høiere temperaturer.

Den laveste kobbergehalt som vi hittil har iakttatt i gangkis med svovlgehalt 30 % eller derover, er omkring 0,10 %. Den laveste selengehalt, vi har iakttatt i meget kobberfattig gangkis, er 7 g/t. Sikkert er således i almindelighet gangkisen såvel kobberførende som selenførende.

Selen inngår i de forskjellige sulfider alltid isomorft som erstatning for svovl.

Man har lenge visst, at gangkisen er koboltførende. Koboltgehalten i f. eks. Løkkens eksportkis er 0,07 %. Og denne koboltgehalt er leilighetsvis blitt utvunnet og nyttiggjort. Foslie har i sitt arbeide om Norges svovlkisforekomster referert endel koboltgehalter i kis efter opgave fra grubene (2). Midlet av disse gehalter er ca. 0,06 %. Endel av analysene har imidlertid ved kontrollanalyser av moderne eksportprodukter vist sig å være mindre pålitelige, noen er for høie og noen er for lave. Men gjennemsnittsgehalten i norsk svovlkis, stykkis eller konsentrat, synes å ligge temmelig nær 0,06 %. Den høieste koboltgehalt, som jeg hittil har konstatert i norsk svovlkiskonsentrat, er i svovlkiskonsentrat fra Fosdalen jernmalmforekomst. Her er koboltgehalten 0,22 %. Det er den samme gehalt som i Outokumpu, som er kjent for å være særlig koboltrik. Men Fosdalen regnes i genetisk henseende ikke til fjellkjedens kisforekomster, men til grunnfjellets jernmalmforekomster. Av omtrent samme størrelsesorden er også koboltgehalten i en svovlkiskrystall fra en pegmatitgang i Iveland.

	S i %	Co i %	Ni i %	Co : Ni
Eksportkis, Løkken	42,50	0,06	0,002	30 : 1
Svovlkis, Skorovas	51,56	0,06	spor	
Svovlkis, Sara gr.	41,60	0,06	0,00	
Svovlkis, Tårstad	52,47	0,05	0,00	
Svovlkisbolle, Sulitjelma	51,46	0,07		
Svovlkiskrystal, pegmatitgang	ca. 52,00	0,24		
Magnetkis, Mugg-gr.	ca. 30,00	0,04	0,00	
Svovlkiskonsentrat, Fosdalen	48,82	0,22	0,02	11 : 1

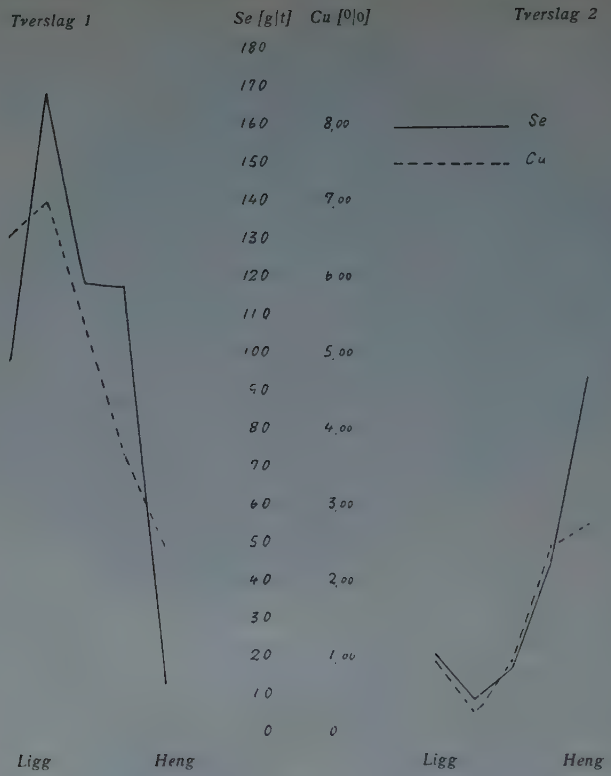

Fig. 3.

Der foreligger dessverre forholdsvis få nikkelanalyser av norsk kis. Fra Løkken har vi endel nikkelanalyser av eksportkisen, som viser at vektsforholdet Co : Ni i denne kis gjennemgående ligger omkring 30 : 1. Thorolf Vogt sier i sitt kisarbeide fra 1935, at typisk norsk svovlkismalm inneholder omtrent 0,02 % nikkel og 0,2 % kobolt (3). Begge disse tall er imidlertid sikkert for høie.

I den øvre jordskorpe er det gjennemsnittlige vektsforhold Ni : Co, ifølge Goldschmidt, 2,5 : 1 (4). I våre typiske magmatiske nikkelforekomster er ifølge British American Nickel Corporation forholdet Ni : Co = 20 : 1 (1921) og ifølge J. H. L. Vogt 12,5 : 1 (5). I våre gangkisforekomster synes altså dette forhold å være omtrent omvendt, således i Løkkens eksportkis 1 : 30. Kobolt er i motsetning til nikkel nesten utelukkende anriket i restopløsningene, derimot neppe noen gang i de først utkrystalliserte mineraler (G. Berg).

Alle våre gangkiser synes altså å være koboltførende. Kan nu kobolt benyttes som skillemiddel mellem gangkis og vasskis? Det viser sig ved analyser av vasskisen i Trondheimsfeltet at koboltgehalten alltid er under 0,01 %, antakelig er den i almindelighet kun tilstede som spor. I Bymarkgruppens sedimentære svovlkisforekomster er således koboltgehalten som regel yterlig liten.

Kvalitative spektralanalyser av gangkiser og vasskiser, som på min anmodning velvilligst er utført av professor Goldschmidt ved ingeniørene Myhren og Kvalheim, har på en meget karakteristisk måte bekreftet min opfatning av de forskjellige kistypers koboltgehalt. Gangkisanalysene viser således svake til middels sterke koboltlinjer, mens samtlige vasskiser viser meget svake koboltlinjer. Både gangkiser og vasskiser viser meget svake nikkellinjer.

I en rekke av våre gangkisforekomster optrer som bekjent lokale anrikninger av magnetit. Vi kjenner slike magnetitpartier bl. a. fra Kjøli, Røstvangen, Løkken osv. I almindelighet er magnetitpartiene gjennemsatt av årer og ganger av svovlkis, de er således med sikkerhet noe eldre enn kisen. Av interesse for disse magnetitpartiers genesis har jeg latt analysere et magnetitkonsentrat fra Løkken på kobolt. Det viste sig at magnetitkonsentratets koboltgehalt var 0,00 %. Spektralanalytisk undersøkelse av Goldschmidt har vist spor? Koboltgehalten i magnetit fra magnetitanrikning i hovedgruben på Løkken er således sikkert null eller meget nær null. Det er altså en vesentlig forskjell mellem koboltgehalten i kis og koboltgehalten i magnetit.

Kobolt inngår i svovlkisen alltid isomorft som erstatning for jern.

Man har lenge kjent til, at de norske gangkiser holder små mengder sølv og gull, som i almindelighet følger kobberkisen. Kobberholdig svovlkis (eller rettere: kobberkisholdig svovlkis) med et par % kobber holder i almindelighet omkring 0,2 g/t gull. Sølvgehalten er gjennemgående 80 ganger så høi. Vektsforholdet Cu : Ag ligger således i almindelighet omkring 1500 : 1 og vektsforholdet Cu : Au i de fleste tilfeller omkring 120 000 : 1 (d. v. s. bessemerkobber av norsk kis holder gjennemgående 0,6—0,7 kg/t sølv og omkring 8 g/t gull).

Av vasskis foreligger der dessverre forholdsvis få gull- og sølvanalyser. Materialet er for litet til, at vi kan trekke generelle slutninger. Men av det, som hittil foreligger, synes å fremgå, at både gull- og sølvgehaltene gjennemgående er endel lavere i vasskis enn i gangkis.

Den kvalitative spektralanalyse er i overensstemmelse med denne opfatning. Analyser av gangkis viser således middelsterke til sterke sølvlinjer, analyser av vasskis viser meget svake til usynlige sølvlinjer.

Zinkgehalten ligger i de fleste tilfeller betydelig lavere i vasskis enn i gangkis. I vasskisen ligger den således antakelig gjennemgående under 0,25 %. I overensstemmelse dermed viser en generalanalyse av Stord-kisen 0,08 % zink. I gangkiser er derimot zinkgehalten sterkt vekslende — i almindelighet ligger den mellem 0,3 og 3 %. Analyse av Løkken grubes eksportkis viser ca. 1,7 % zink. Zink inngår i våre kisforekomster alltid i form av zinkblende.

Den gjennemsnittlige cadmiumgehalt i zinkblende i Bymark-gruppens gangkis synes efter det forholdsvis ubetydelige materiale, som foreligger, å ligge mellem 0,20 og 0,30 %. Vektsforholdet Zn : Cd i zinkblenden er således gjennemgående omkring 200 : 1. I jordskorpens eruptivbergarter er vektsforholdet Zn : Cd = 80 : 1, i kisens zinkblende er således zink sterkere anriket enn cadmium.

Zinkblendens jerngehalt er sterkt vekslende. I våre magnetkisfrie svovlkisforekomster (Løkken, Skorovass) er jerngehalten neppe mere enn 1 à 2 %.

Blygehalten er i begge kistyper alltid helt ubetydelig, i mange tilfeller absolutt null. Gjennemgående ligger den dog sikkert lavest i vasskisen, hvor bly som regel ikke kan påvises. I generalanalyser av eksportkis fra Løkken er bly kun angitt som spor. Men i enkelte gangkiser, således i gangkis fra Undals grube, når blygehalten helt op i et par % (ifølge generalanalyse av stykkmalm). En slik blygehalt må imidlertid i norsk kis betegnes som usedvanlig høi. Bly inngår i våre kisforekomster alltid i form av blyglans.

Arsengehalten synes efter det foreliggende analysemateriale å være av omtrent samme størrelsesorden i begge kistyper. Arsengehalten i gangkisene ligger i de fleste tilfeller mellem 0,04 og 0,07 %. I vasskisen ligger den gjennemgående en ubetydelighet høiere, omkring 0,08 %. En enkelt generalanalyse av Stord-kisen viser en arsengehalt av 0,09 %, hvilket må betegnes som en relativt høi arsengehalt i norsk eksportkis.

Jordskorpens gjennemsnittlige arsengehalt er, ifølge Goldschmidt, 5 g/t. Mens våre nikkelmagnetkiser er meget arsenfattige, har der således i våre gangkiser funnet sted en arsenkonsentrasjon på 100 eller litt derover. Arsen er jo et element, som er særlig karakteristisk for restopløsningene.

Den relativt sterke konsentrasjon av arsen i de sedimentære kisforekomster er allerede tidligere konstatert av Goldschmidt og Peters. „In den Sedimentgesteinen wird Arsen nicht nur in Verknüpfung mit der Ausfällung von Eisenhydroxyden angereichert, sondern auch zusammen mit Sulfiden des Eisens“, sier Goldschmidt og Peters i „Zur Geochemie des Arsens“ (6). Arsen inngår antakelig isomorft i svovlkis som erstatning for svovl. Arsenkis kan i almindelighet ikke iakttas.

Gehalten av fosfor er i almindelighet lav i begge kistyper. Antakelig er den — likesom arsengehalten — gjennemgående litt høiere i vasskisen enn i gangkisen. Mens fosforgehalten i gangkis i en rekke tilfeller ligger omkring 0,01 %, litt over eller litt under dette tall, ligger den i vasskis i almindelighet mellem 0,02 % og 0,04 %, til dels også derover. Analyse av vasskis fra Leksdalen viser i overensstemmelse dermed 0,020 % fosfor. Generalanalyser av Stord-kisen viser betydelig høiere gehalter, 0,06—0,08 % fosfor.

Den gjennemsnittlige fosforgehalt i jordskorpens eruptivbergarter er ca. 800 g/t. Den gjennemsnittlige fosforgehalt i en rekke ler-sandsedimenter er, ifølge Goldschmidt, ca. 700 g/t (7). Alle våre gangkiser viser således en betydelig lavere fosforgehalt enn eruptivbergartene. Og våre vasskiser viser også i de aller fleste tilfeller en vesentlig lavere fosforgehalt enn ler-sandsedimentene. Mens de sedimentære jernoksydmalmer i almindelighet viser en „anrikning“ av fosfor, viser altså de sedimentære jernsulfidmalmer i almindelighet en „fortynning“ av fosfor. Fosfor inngår i våre kisforekomster antakelig alltid i form av apatit.

De geokjemiske undersøkelser av Trondheimsfeltets 2 interessanteste kistyper, gangkisen og vasskisen, har på alle punkter bekreftet den opfatning, som jeg tidligere på geologisk-petrografisk vei er kommet til, nemlig at gangkisen er hydrotermal, hydrotermal metasomatisk, og at vasskisen er sedimentær, sedimentær biokjemisk. Der finnes blandingsledd mellem disse 2 typer, fremkommet på den måte, at gangkisopløsninger, som yngre opløsninger, har trengt inn i og gjennemvevet vasskislagene som de eldre lag. Men *primært* er der 2 helt forskjellige, distinkt adskilte kistyper av forskjellig alder.

Jeg vil til slutning få bringe direktør Kiær, Løkken Verk, min beste takk for at han har tillatt offentliggjørelse av endel data fra Verkets kisforekomster i Meldal.

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I ordskiftet efter foredraget deltok L. Størmer, V. Goldschmidt, S. Foslie, Th. Vogt, K. Kristoffersen og foredragsholderen.

H. H. SMITH, som ikke kunde være til stede på møtet, sendte inn en oppgave over analyser av norske malmer.

A/S Skorovas Gruber. 1913—1920.

Sammanställning över Arsenik- och Selen-Analyser.

Dato	Firma	Resultat
2. dec. 1913.	Norsk Kem. Bureau	As 0,030 %
20. aug. 1914.	—»—	Se spår
		As 0,012 -
		As 0,015 -
		As 0,018 -
		As 0,028 -
10. sept. 1914.	—»—	As 0,012 -
10. mars 1915.	—»—	As 0,023 -

Dato	Firma	Resultat
19. april 1915.	Kgl. Tekn. Högskolan, Stockholm	As 0,005 % Se 0,005 -
17. mai 1915.	Lippman Bloch. Av Dr. Lewkowitz, Breslau. As. ganz geringen Mengen.	
21. mai 1915.	Edward Riley & Harbord, London	As 0,042 - Se Nil.
27. mai 1915.	Sulman & Piccard, London. (By Marsh test)	As Trace Se Nil.
7. juni 1915.	Geo. Rudd Thompson, Newport	As 0,0050 - Se 0,0079 -
10. juli 1915.	Edward Riley & Harbord, Londvn	Se 0,0022 -
15. juni 1917.	Norsk Kem. Bureau .... General analys på prov från en rad borrkärnor, men här ingår ej kis från Nygruvan och Gamlegruvan. Det anmodades om bestämning på event. selen.	As 0,0400 -
7. juli 1920.	Olaf Røer	As 0,038 -
30. juli 1920.	Edward Riley & Harbord, London	As 0,020 -
	I ett senare insänd prov fann firman	Se 0,0022 -

General prov tagna juli 1914. (H. H. Smith.) Gamlegruben, Stollen:

51,32 % S
0,40 » Cu
0,26 » Zn
0,012 » As
45,35 » Fe
1,93 » SiO_2

samt obetydligt Al_2O_8, CaO och MgO.

Nygruben, Stollen:

% S	% Cu	% As	% Ouppl.
48,20	0,68		4,98
50,40	0,23	0,015	2,76
50,66	0,66		3,10
51,70	spår		1,80
51,60	0,05		1,72
51,76	spår		1,32
51,60	0,28	0,018	2,00
50,38	spår		3,64
50,88		0,028	2,40

Genomsnittsprov av borrkärnorna och i denna analys ingår ej kis från Nygruben och Gamlegruben samt all kis är medtagen som höll över 40 % S:

46,40 % S
0,98 - Cu
0,89 - Zn
0,04 - As
41,35 - Fe
1,52 - Al_2O_3
4,63 - SiO_2
1,08 - CaO
1,32 - MgO

98,21 % + CO_2 och alkalier.

Provleverance på 340—450 ton Nygrube-kis sänt till Sverige sommaren 1915:

Analys av avbrand. Torkad vid 105° C.

	Svavel %	Jern %	Koppar %	Zink %	
Ströms Bruk	1,23	64,1	0,36	0,19	Kgl. Tekniska Högskolans Materialprovningsanstalt
Öhrvikans A/B	2,7	64,9	0,31	0,15	Do.
Mackmyra	1,27			0,48	Do.
Hismofors	0,88				Do.
Do.	0,49	65,9	0,35	0,27	Do.
Ströms Bruk	1,14	64,6	0,29	0,276	3,48 % SiO_2. P. icke spår. Norsk Kemisk Bureau

Av ett större parti kis från Nygruben blevo lika stora mängder sända till olika analysfirmor samtidigt för kontrollens skull, som även anges här nedanför.

Analys utförd av Edward Riley & Harbord, London 21. mai 1915.
Sample dried at 100° C.

Sulphur	50,73	%
Sulphuric Acid	0,60	-
Sulphate of Baryta	Traces	
Iron	44,36	-
Protoxide of Iron	0,54	-
Paroxide of Iron	0,91	-
Arsenic	0,042	-
Copper	0,30	-
Nickel	0,08	-
Lead	Traces	
Zinc	»	
Silica	1,25	-
Alumina	0,45	-
Oxide of Manganese	Nil	

Lime	0,12 %
Magnesia	0,30 -
Phosphoric Acid	0,014 -
Selenium	Nil[1]
Carbon Dioxide	Traces
Combined Water	0,40 -
	100,096 %

Equal to Total Sulphur	50,97 %
» » Total Iron	45,42 -
» » Phosphorus	0,006 -

Analys utförd av Sulman & Piccard, London, 27. mai 1915.

Insolubles	1,30 %
Sulphur (unoxidised)	51,00 -
Iron	45,50 -
Lime	0,12 -
Copper	0,30 -
Phosphorus (AsP_2O_5)	0,056 -
Sulphur Trioxide (SO_3)	0,48 -
Oxygen, water, and loss	1,244 -
Arsenic (by Marsh test	Trace
Antimony. Tellurium	Nil
Selenium	Nil
Bismuth	Nil
Fluorine	Nil
	100,000 %

Note: 1,05 % of the iron was present in oxidised form probably as basic sulphate.

The total sulphur was 51,19 %: i. e. inclusive of SO_3. Some water was still detected after drying at 100° C. for four hours.

Analys utförd av Geo. Rudd Thompson, Newport, 7. juni 1915.
Mineral dried at 100° C.

Iron	44,8000 %	= Total Iron 45,35 %
Peroxide of Iron	0,6400 -	
Sulphur	51,3200 -	
Silica	1,5000 -	
Lime	1,0000 -	
Magnesia	0,4700 -	
Copper	0,2880 -	

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[1] Selen kunde ej påvisas. I et senare insänd prov fann R. & H. 0,0022 % Se.

Phosporic Acid	0,0090 %	= Phosphorus 0,004 %
Arsenic	0,0050 -	
Selenium	0,0078 -	
Titanic Acid	0,0170 -	
Nickel, Cobalt, Zinc .	None	
Baryta. Chromium ..	None	
Lead	Traces less than 0,005 %	
Free Carbon	None	
Carbonic Acid	Trace	
	100,0569 %	

Utom dessa fullständiga analyser, lät jag, under tiden jag hade befattning med Skorovas ännu en sådan utföras i Sverige, och som var min första.

Analys utförd av den Kungl. Tekniska Högskolans Materialprovningsanstalt, Stockholm, 19. april 1915.

På torrt prov.

Svavel	51,4 %
Järn	45,7 -
Koppar.........................	0,31 -
Zink	0,07 -
Kiselsyra	1,3 -
Arsenik	0,005 -
Selen	0,005 -

Finbur kisförekomst.

Genomsnitts prov från dagskäringar på 1,5—2 m mäktighet och från året 1913.

S	44,4 %
Cu	0,8 -
Zn	2,8 -
Fe_8O_4	7,7 -
Ouppl.	6,8 -

Nedanstående analyser äro från synken på 13,25 m djup och över en mäktighet på kisen av 2,8 m. (H. H. Smith.)

	Häng	Midt	Ligg
Malmmäktighet	1,3 m	1,0 m	0,5 m
	%	%	%
S	45,05	46,50	42,91
Cu	0,92	1,99	0,76
Zn	0.93	1,42	5,06
Ouppl.	3,96	5,40	12,48

A/S Rødfjellets Kisgruber.

Prov på anstående kis i olika delar av gruvan mars 1918 (H. H. Smith).

A.	50,88 % S	3,20 % ouppl.
B.	49,60 - »	3,82 - »
C.	50,93 - »	3,72 - »

Proven visa, att Rødfjellets kis är hittills den rikaste svavelkis, som Norge har anstående.

En seri prov analyserade och deras genomsnittsanalys höll:
År 15. mars 1917.

SiO_2	1,71	%
Cu	0,51	-
Zn	1,08	-
Fe	45,25	-
S	50,50	-
As	0,014	-
	99,06	%

+ lite Al_2O_3, CaO och MgO.

Generalanalys av 711 ton styckmalm skeppad 13. juni 1911. Analys utförd av Stockholms Bergtekniska Laboratorium.

Svavel	50,88	%
Selen	0,001	-
Arsenik	0,001	-
Järn	45,00	-
Koppar	0,66	-
Zink	1,04	-
Lerjord	0,50	-
Kalk	0,29	-
Magnesia	0,12	-
Kiselsyra	1,48	-

Kisavbrand (Mackmyra). År 13. januari 1917.

Fe	61,72	%
Cu	0,44	-
Zn	1,56	-
SiO_2	5,03	-
S	2,41	-
P	Spor	

Med undantag av skeppningsanalysen äro alla utförda av Norsk Kemisk Bureau.

A/S Svanø Gruber.

Genomsnittshalten på råmalmen kan sättas till 15,5 % och 0,84 % Cu. Typiska analyser på exportmalmen visa: (H. H. Smith.)

S	44,03 %	och	44,90 %
Fe	40,10 -	»	37,90 -
Cu	2,05 -	»	1,84 -
Zn	2,61 -	»	4,22 -
As	0,009 -	»	0,015 -

Selen analys föreligger ej.

Kisförekomst Meldalen.

En provstuff, som innehöll turmalin i kis blev analyserad med resultat:

Svavel	45,20 %
Arsen	0,04 -
Silver	15 och 20 g pr. ton kis.

Analysen er utförd av Klüvers Kemiska Bureau, och provet av H. H. Smith.

Bestämning av selen i kiser

av Peter Klason och Hjalmar Melquist.

Arkiv för Kemi, Mineralogi och Geologi. Band 4. Nr. 29. Januari 1912.

I Norsk geologisk tidsskrift 15, 1935, p. 320—324 har jag redan tillåtit mig henvisa til ovenstående artikel, och ber åter i dag få hänvisa till den i förbindelse med arsen och selen. Från artikeln citeras endast något lösryckt sålunda:

Anmärkningsvärdt är också, att Se-halten i bränderna är betydligt större vid koppar- och blyhaltiga kiser än vid kiser fria från dessa metaller, vilket torde bero derpå att selenet av bly och koppar är i hetta beständigare än av järnoxid. Ju renare således kisen är desto lättare och fullständigare avger den vid rostningen både sitt svavel och selen. Bränderna av de kopparhaltiga kiserna voro dessutom mer eller mindre starkt sammansintrade i klumpar, under det att de kopparfria voro pulverformiga och ljusare till färgen. Vid en del kiser, som hade en synnerligen väl utbildad kristallinisk struktor som n:is 3 och 10, inträffade vid rostningen en stark volymökning av rostgodset. Alla de undersökta kiserna höllo arsenik och en del tellur.

Ytterligare anföres: Grabe och Petren funno i 8 st. generalprov av Falukis resp. 50, 50, 60, 100, 110, 120 och 130 g i medeltal 86 g selen pr. ton kis och i 8 st. prov av Norsk kis resp. 60, 60, 70, 140, 70, 70, 40 och 40 g i medeltal 67,5 g selen pr. ton kis. En kis från spansk fyndighet innehöll 70 g selen pr. ton. Såsom synes variera de av oss funna selenhalterna mycket mera i våra kisprov än i deras. Vi tro ock att i verkligheten varierar selenhalten i kiserna mycket mera än som man

kunde ha anledning förmoda av deras analyser. Selenet är nämligen bundet vid särskilda bly- och vismuthaltiga mineral, som tydligen kunna finnas på mycket ojämnt sätt fördelad i kisen. Erfarenhet från sulfitcellulosafabrikerna talar också för en sådan variation. Detta anförande är från ett försök av Grabe och Petren.

GENERALFORSAMLING OG MØTE TORSDAG 13. FEBRUAR KL. 18

Til stede 43 medlemmer og 8 gjester.

Formannen refererte hilsningsskrivelser fra Geologiska föreningen i Stockholm og professor Harry von Eckermann.

GENERALFORSAMLING

Årsmelding for 1940.

Siden forrige generalforsamling er det utgått 2 medlemmer:

W. C. Brøgger,
Johan Normann

som begge er avgått ved døden.

I samme tidsrom er innvalt 13 nye medlemmer:

225. Jens A. W. Bugge, Norges tekniske høgskole, Trondheim.
226. Per Holmsen, Norges geologiske undersøkelse, Oslo.
227. Henrich Neumann, Norges geologiske undersøkelse, Oslo.
228. Hans C. Hansen, Midtstua, Kihlsbakken, Kambo.
229. Gunnar Semb, Norges landbrukshøgskole, Ås.
230. Kristoffer Kristoffersen, Geologisk museum, Oslo.
231. Worm Hirsch Lund, Jacob Fayes veg 2, Bygdøy.
232. Worm Lund, Kongens gate 5, Oslo.
233. Brit Hofseth, Fagertunvegen 4, Bestun.
234. Ivan Th. Rosenqvist, Schwensens gate 6, Oslo.
235. Arthur O. Poulsen, Niels Henrik Abels veg 31, Blindern.
236. Gunnar Henningsmoen, Observatorie terrasse 56, Oslo.
237. Robert Major, Kirkevegen 68, Oslo.

Medlemstallet er nu 142, hvorav 57 livsvarige og 85 årsbetalende medlemmer.

Det er som vanlig holdt 6 ordinære møter. Til gjengjeld for, at aprilmøtet måtte innstilles, er det holdt 3 møter i høstsemestret. Det samlede frammøte var etter møteprotokollene 189 personer. Søndag 2. juni blev det holdt en ekskursjon til Grefsenåsen under ledelse av O. Holtedahl. Det var ca. 20 deltakere, hvorav en del medlemmer av Geologisk amatørklubb.

Av tidsskriftet er i året utkommet bd. 19 h. 4 og bd. 20 h. 1—2.

Regnskap for 1940.

Inntekt:

Beholdning overført fra 1939		kr. 1 199,86
Medlemskontingent for 1938, 1939 og 1940		» 320,00
Renter fra livsvarige medlemmers fond for 1940		» 180,32
Tilskot fra staten		» 400,00
Tilskot fra Sulitelmafondet		» 3 100,00
Ekstra trykkingstilskot:		
Fra Nansenfondet til L. Størmer:		
Early Descriptions, bd. 20 h. 1—2	kr. 400,00	
Fra Nansenfondet til L. Størmer og Th. Vogt:		
Dictyonema Shales, bd. 20 h. 3—4	» 350,00	
		» 750,00
Abonnement og salg av tidsskriftet 1940		» 219,00
Renter av bankinnskot 1940		» 4,43
		Kr. 6 173,61

Utgift:

Tidsskriftet:		
Trykking bd. 18 h. 4, rest	kr. 955,67	
» bd. 19 h. 1	» 1 891,03	
» bd. 19 h. 2—3, avdrag	» 1 608,97	
Tegnearbeide	» 4,50	
		kr. 4 460,17
Klisjeer, bd. 19 h. 4, rest	kr. 16,16	
» bd. 20 h. 1—3	» 531,57	
		» 547,73
Arbeidshjelp, porto, skrivesaker		» 398,49
Møter, representasjon		» 241,44
Rabatt på salg av tidsskriftet		» 53,67
Forvaltning av statsobl., livsv. medl. fond		» 5,00
Overført til 1941		» 467,11
		Kr. 6 173,61

Status pr. 2/1 1941.

Livsvarige medlemmers fond. Urørlig kapital.			
Statsobligasjoner	kr. 3 500,00		
Bankinnskot	» 1 165,00		
		kr. 4 665,00	
Utestående kontingent			kr. 630,00
Beholdning			» 467,11
			Kr. 1 097,11

Regnskapet var revidert av S. Føyn og H. H. Smith og blev godkjent etter bemerkninger av N. H. Kolderup, K. Münster Strøm, J. Helverschou, C. Bugge, Th. Vogt og formannen.

Regnskapsførerens løn for 1941, kr. 200,00 blev godkjent.

Valg av styre for 1941.

Formann	L. Størmer
Redaktør	H. Rosendahl
Sekretær	T. Strand
Styremedlemmer	K. Münster Strøm C. W. Carstens
Varamann	J. Helverschou

Revisorene H. H. Smith og S. Føyn blev gjenvalt.

Til medlemmer av Reuschmedaljekomitéen blev valt A. Bugge og Th. Vogt.

Reuschmedaljen.

Reuschmedaljen blev utdelt til lektor Sven Føyn for hans avhandling: „The Eocambrian Series of the Tana District, Northern Norway“, Norsk geol. tidsskr. 17, 1937, s. 65—164.

Arbeidet gir mange viktige iakttakelser fra et stort og geologisk lite kjent område. Det bringer i stor utstrekning klarhet over de stratigrafiske forhold. Ved petrografiske iakttakelser er påvist interessante trekk, bl. a. ved tillittenes dannelsesmåte. Nye fossilforekomster er oppdaget og visse tektoniske hovedtrekk er klarlagt. Avhandlingens form er klar og konsis. Arbeidet tilfredsstiller således fullt ut de krav som statuttene for Reuschmedaljen stiller. — Det kan også nevnes at Reusch selv i sin tid arbeidet innen samme område.

Føyn takket for den påskjønnelse, som det var for hans arbeide, at medaljen var tildelt ham.

MØTE

Foredrag.

Arne Bugge: **En oversikt over arbeidet i det sydnorske grunnfjell.**

Nye iakttakelser — som ennu ikke er publisert — har jeg særlig gjort under kartlegging av Kristiansands rektangelblad og ved undersøkelse av enkelte kvartsitt- og kalkstensforekomster i traktene nordøstover fra Lillesand. Ennvidere har jeg foretatt en rekke undersøkelser av molybdenforekomster i det syd-vestlige Norge. Mellom Mjøsa og Randsfjorden har jeg ved et par korte befaringer gjort meg bekjent med bergartene på hver side av rivningsbreksjen nord for Brandbu.

Jeg fastholder den opfatning, jeg i tidligere publikasjoner har framlagt om Kongsberg—Bamble-formasjonens dannelse, idet jeg hverken ved mine nyeste undersøkelser eller ved innvendinger, som er framkommet fra andre geologer, kan finne nogen faktiske oplysninger, som bringer meg i tvil om riktigheten av grunntrekkene i den opfatning som jeg har publisert om formasjonens tilblivelse.

Som hovedlinjene for mitt syn på grunnfjellsformasjonene kan jeg resumere:

Kongsberg—Bamble-formasjonen kan betraktes som et segmentformet utsnitt av et stort — nu forsvunnet — erupsjonsområde. Den ytre bue dannes av en linje fra Randsfjorden langs Oslofeltets vestgrense og Skagerakkysten til Kristiansand. Den indre begrensning dannes av den store rivningsbreksje, som går i en noget bøiet linje fra sydenden av Sperillen til Kristiansand (linjen er et kort stykke avskåret av Oslofeltet syd for Kongsberg). Fra sydenden av Sperillen bøier begrensningen over mot Jevnaker.

Jeg betrakter det ved de her nevnte linjer begrensede parti som et lite utsnitt av et erupsjonsområde som i de perifere deler har vært omgitt av en hydrotermal og pneumatolytisk randsone.

„*Kongsberg-formasjonen*“ betrakter jeg som en del av det indre erupsjonsområde og *Bamble-formasjonen*“ som en til dette hørende hydrotermal sone karakterisert ved en gjennomgripende metasomatose.

Idet jeg finner at begge bergartsgrupper hører til samme cyklus, har jeg samlet dem under navnet „Kongsberg—Bamble-formasjonen“.

Kongsberg—Bamble-formasjonens eruptiver anser jeg å være trengt fram i eldre bergarter, som jeg har samlet under navnet, båndgneis. Kun ved Kongsberg er der kjent partier av båndgneisen, som har kunnet utskilles i typer, som av Carl Bugge er beskrevet som effusiver og sedimenter.

Ved senere inntrengen av diorittisk og granittisk magma har bergartene tapt sin oprinnelige karakter og er mange steder forvandlet til migmatitter.

Under mine kartlegginger og befaringer har jeg, på strekningen mellom Randsfjorden og Kristiansand ikke sett noe parti i båndgneisen, som jeg har kunnet utskille som sikre suprakrustaler.

Da de utstrakte diorittinjeksjoner i båndgneisen var avsluttet, kom en inntrengen av noritt og gabbroganger (olivinhyperitt, vinordiabas, amfibolittganger) som i den indre del av erupsjonsområdet viser seg som større massiver og ganger og i den yttre del vesentlig som mer og mindre omvandlede gabbroklumper. (Olivinhyperitt og gabbroganger er der forholdsvis sjelden.)

I forbindelse med de små gabbromassivers framtrengen i den yttre sone begynte en veldig cirkulasjon først av høitemperaturopløsninger, senere av lavtemperaturopløsninger, som ledet til dannelsen av den efter min opfatning hydrotermale randsone, som har vært kalt Bamble-formasjonen.

I den tid da de forholdsvis høie temperaturer var enerådende er granittmagma størknet i massiver og ganger. De siste omslutter mange steder gabbroklumpene samt den ved dem påbegynte metasomatose. I forbindelse med granittmagmaens framtrengen finner man flere steder palingent dannede overgangsbergarter som ofte er av charnockittisk type.

I den ytre sone opfatter Jens Bugge sådanne overgangsbergarter som metasomatiske. (Arendalitter.)

Granittgangene viser — særlig ved gabbroklumpene — overgangstyper som i strukturen skifter fra aplittisk til pegmatittisk og kvartsmengden skifter langs strøket og tvers på strøket således at man med en overgang gjennom granittslirer langs strøket og tvers på strøket kommer over i urene kvartsitter og glimmerskifere.

I den yttre sone omkring de små gabbro- og granitt-massiver ser man ofte i den vestlige del av Bamble-formasjonen at der efter granittgangenes og massivenes størkning er trengt fram granittiske magmaopløsninger som er størknet som veldige pegmatittganger der ofte som svermer helt omslutter de centrale gabbro-granittkjerner.

Særlig i Bamble—Kragerø-trakten er det alminnelig at apatittganger, som er eldre enn pegmatittgangene omslutter gabbroklumpene.

Bor og klor har i rikelig mengde vært tilstede i gassartene og opløsningene og man finner nu deres virkninger i store mengder turmalin og skapolitt. Turmalin i granitter, kvartsitter, glimmerskifere og pegmatitter. Skapolitt i gabbroer som skapolitthornblendesten og i skarnmineralene.

Jernmalm finnes som magnetitt i og ved de omvandlede gabbroers randsone i forbindelse med skarndannelse. Disse forekomster, som alltid optrer i forbindelse med — til dels omsluttende — granitter, er som påpekt av Th. Vogt noe manganførende, hvilket er naturlig på grunn av den nære forbindelse med granitt.

Granitten gjennomskjærer til dels skarnmineralene. Pegmatittgangene gjennomskjærer malm og skarn.

Jernglans og magnetitt forekommer sammen med magnesitt, dolomitt og kalkspat på Langø ved Kragerø i ganger som er yngre enn pegmatittgangene. Dessuten forekommer jernglans i den nordlige del i Modum, i kvartsitt på grensen mot gabbro.

Hvorvidt sedimentære kalkstener i båndgneisen har spillet noen rolle ved den eldste skarndannelse, kan jeg ikke uttale mig. Det er selvfølgelig mulig, men jeg har ikke sett noe bevis for at man ved jernmalmforekomstene har forskarnede kalkstenslag av lignende type som beskrevet fra de mellomsvenske gruber. For øieblikket kan jeg ikke se at man sikkert kan avgjøre, *hvorfra* skarnforekomstene har fått sin kalk. Om de sirkulerende opløsninger har fått sitt kalkinnhold fra sedimentære nu ukjente kalkstenslag eller de har fått det ved gjenopløsning av anortitt. Det forekommer meg dog å være naturlig å tenke seg, at kalkspat er dannet efter spilittreaksjonen, da man derved også får forklaring på de albittbergarter som man finner i den midtre del av det her behandlede hydrotermale område og den enorme albittgjennomvevning, som man finner i den nordlige del.

At også karbonater har forekommet i de opløsninger, som har cirkulert før og efter pegmatittdannelsen mener jeg må være fastslått ved de til dels rene karbonatganger, som er kjent i og ved så mange av

Bamble-formasjonens gabbroklumper og olivinhyperitter. Kalkspattklumper i pegmatittganger er også kjent i den nordlige del av feltet. Ved Bjorvatn i Herefoss har kalkspat også vært ledsaget av kiselsyreopløsninger som har avsatt rene kvartsmasser i et par meters bredde på hver side av ganglignende kalkspattansamlinger i og ved gabbromassiver. Kalkspattansamlingene kan ha en bredde av 7—8 m.

I den nordlige del av den hydrotermale sone (ved Gampehue i Sigdal) finnes en ren kalkspattforekomst i en omvandlet gabbro som er opfylt av kalkspatt i små inneslutninger og småårer.

De største kalkspattansamlinger finner man på småøyene syd-vestover fra Grimstad. Særlig disse kalkstensforekomster ansees å være av sedimentær oprinnelse. Jeg kan ikke se, at de adskiller sig så meget fra kalkspattgangene i gabbro, at der er noen grunn til å sette dem i en særklasse, da også disse optrer ved de ofte sterkt epidotiserte amfibolitter som danner en fortsettelse av de gabbrobergarter, som ledsager jernmalmforekomsten ved Arendal.

Når man betenker, at jeg ikke har sett skarnmineraler i kalkstenen og at ingen andre, som har beskrevet disse og andre kalkstensforekomster av samme type, har angitt finnesteder for skarnmineraler, så må man være på det rene med, at de må være meget sjeldne.

Det er da vanskelig å oprettholde en opfatning om, at de mange kalkstensforekomster ved gabbroklumper og til dels olivinhyperitter er rester av gamle sedimentære kalkstenslag.

Det faktum, at man kjenner eksempler på så gasfattige gabbromagmaer, at de ikke har dannet reaksjonsmineraler langs eldre kalkstenslag, kan neppe gi en tilfredsstillende forklaring av de manglende reaksjonsmineraler ved Bamble-formasjonens kalkstener, da denne formasjon er karakterisert ved cirkulasjon av gasrike opløsninger, hvori klor har vært særlig framtredende og har overalt ellers deltatt i skapolittdannelsen. Man skulle her nettop vente en utpreget skarndannelse og man skulle ikke vente i Bamble-formasjonen å finne undtakelse fra de erfaringer vedrørende arkeiske amfibolittganger, som Eskola uttrykker i „Die Entstehung der Gesteine“ 1938, hvor han resymerer, at de arkeiske amfibolittganger nesten bestandig har en kontaktrand av forskjellige kalksilikatmineraler ved grensen mot krystallinsk kalksten. Heller ikke skulde man vente å finne en så utpreget motsetning til forholdene ved mellomsvenske gruber, hvor man ifølge N. Magnusson alltid finner kalksilikater i kalkstener. F. eks. i Persberg malmtrakt, uttaler Magnusson, at kalkstener og dolomitter fører alltid som forurensninger større eller mindre mengder silikatiske og andre ikke karbonatiske mineraler, og videre, at det skarn som optrer i det vesentlige er bundet til grensene mot den omgivende leptitt.

Kalksten noenlunde fri for kalksilikater kan ved Persberg finnes i midten av større utvidelser av kalkstenslagene. De kan også finnes i betydelig avstand fra amfibolitt og gabbrofeltene, som f. eks. i det av N. Sundius beskrevne felt i Stockholms skjærgård.

Ser man karbonatene dannet ad metasomatisk vei, er det naturlig at der finnes overgangstyper mellom rene skarnansamlinger med litt kalkspatt og rene karbonatganger. En sådan overgangstype er nevnt av Jens Bugge i et lite felt ved Løddesøl.

Hvis man erkjenner, at de manglende reaksjonsmineraler viser, at eruptivene ikke kan være størknet i og ved kalkstenene, og man allikevel vil forsøke å forklare kalkstenene som sedimenter, må de tolkes som kalkstenslag, som i en tektonisk periode er slitt istykker og er ført fram til gabbroene og olivinhyperittene som ombøiede rester av de gamle lag. Det er da i og for sig påfallende, at kalkstensrestene overalt er ført fram til gabbrobergarter.

Dette kunde vel tenkes. Men det er en avgjørende hindring for denne opfatning, at der ikke har forekommet en sådan tektonisk periode *efter* at gabbro—granitt-injeksjonene var avsluttet. Som beviser herfor kan nevnes:

Amfibolittgangene — f. eks. ved Kongsberg — uten noen foldning eller forkastning, de mange gabbro—granitt-injeksjoner med omgivende upressede pegmatittsvermer, ufoldede apatittganger som til dels omslutter gabbromassiver, de upressede skarnmineraler, de skarpkantede granittbreksjer og gjennomvevninger såvel i Kongsberg- som i Bamble-formasjonen, de upressede skapolitthornblendefelser som en del av gabbroklumpene, albittgjennomvevningen og overalt manglende tverrforkastninger av noen betydning, den friske kvarts uten undulerende utslukning.

Med bibehold av alle disse primære tilstander, kan det neppe tenkes at avslitte kalkstenslag kan være presset inn gjennom pegmatittsvermene og inn mod gabbroene.

Hvis man prøver å forklare Bamble-formasjonen som en randmetasomatose rundt det store indre eruptivområde, hvorav jeg anser Kongsberg-formasjonen som en rest, kan jeg ikke se annet enn at Bambleformasjonens tilblivelse kan sees som en harmonisk utvikling, hvor man finner metasomatosens dypeste deler sydligst ved Kristiansand og de nærmest dagen liggende deler nordligst i Modum og Snarum.

Følger man randsonen nordøstover fra Kristiansand, møter man først granitt og gabbroklumper omgitt av pegmatittsvermer og enkelte kalkspattforekomster, men forøvrig ingen mineralisering. Videre mot nordøst og nord viser den stadig økende mengde turmalin og skapolitt, at man mer og mer kommer op i de høiere nivåer hvor bor og klor har kunnet inngå i mineraldannelsen i de omgivende bergarter. Samtidig øker karbonatenes magnesiainnhold, således at man ved Kragerø finner dolomitter og på Snarum betydelige magnesittansamlinger. Rene kalkspatt-anrikninger sees også i utkanten av sonen. SiO_2-anrikede bergarter øker sterkt efter hvert som man kommer nordover. Skarnmineraler og magnetitt særpreger den mtitre del, mens jernglans er jernmineralet i den nordlige del. Sydligst i sonen har man ikke de særpregede albittbergarter, men i den mittre del begynner albittfelser av Kragerøittypen og nordligst finner man som rimelig er i de høiere nivåer av metasomatosen, at alle bergarter er gjennomvevde av albittganger og albittårer.

Samtidig med at turmalinmengden øker nordover mot Snarum, finner man også en jevn økning av kvartsittenes og glimmerskifernes sillimanittinnhold.

Hvis man går tverrprofiler fra Kongsberg-formasjonen over mot den østlige begrensning av Bamble-formasjonen finner man liknende profiler, som når man går langs sonen fra syd mot nord. I Bamble f. eks. treffer man først granitt—gabbro-injeksjoner og, — efterhvert som man går utover, en økende mengde pegmatitt. I granitt og båndgneis begynner en og annen kvartsittslire og båndformige kvartsittmasser å gjøre seg gjeldende. Senere kommer man over i de lange gangliknende kvartsitter (kvartspegmatitter) og de vanlige sillimanittkvartsitter og sillimanittglimmerskifere som karakteriserer bergartene i den ytterste del av sonen. Tvers på strøket fra vest mot øst finner man altså, likesom langs strøket fra syd mot nord, at man jevnt går over fra høitemperatur mot lavtemperatur områder hvor cirkulerende opløsninger og gasarter har satt sitt preg på mineraldannelsen. De metasomatiske prosesser, som har ledet til tilførsel og bortførsel av stoff fra de eldre bergarter (båndgneisene), hvorved de lerjord- og magnesia-anrikede kvartsitter og glimmerskifere er framkommet, er beskrevet av Eskola, Geijer og Sundius. De av disse forskere givne forklaringer av de metasomatiske omvandlinger kan lett innpasses i den lange sone av Bamble-formasjonens bergarter. I Bamble-formasjonen må man i tillegg medta som et for den karakteristisk trekk de pneumatolytiske og hydrotermale processer rundt de mange små-eruptiver og man må der også regne med, at kvarts er dannet gangformig som egne kvartspegmatitter og som kvartsansamlinger i forbindelse med pegmatittganger.

Tom. Barth har som en forklaring av Bamble-formasjonens mineralisering antydet muligheten av en metasomatose fra en underliggende migmatittfront. Jeg kan ikke se at dette resonnement fører fram.

Som tidligere nevnt er det ikke i noget tilfelle påvist, at yngre gabbroer (olivinhyperitter, vinordiabaser og amfibolitter), granitter og pegmatitter har vært utsatt for noen regional metasomatose. Breksjene og gjennomskjæringene er skarpe og uomvandlede og skarnmineralene som er eldre end granittene og pegmatittene, kan ikke sees å være berørt av noen senere omvandling. Dette gjelder granitter og gabbroer både i Bamble-formasjonen og Kongsberg-formasjonen. Dertil kommer som foran nevnt at de egentlige kalkstener er uberørt av nogen som helst metasomatose.

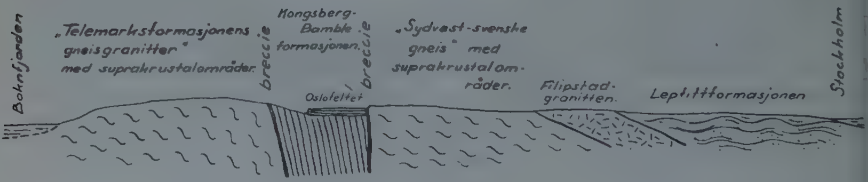
En opstigen av gass fra en dypere migmatittfront forklarer heller ikke den i mitt arbeide „Kongsberg—Bamble-formasjonen“ beskrevne og foran nevnte *sonare* utvikling av de ved metasomatiske prosesser dannede bergarter. Gassartene fra en dyp-migmatisering måtte virke mer regionalt og de kunne ikke i sin virkning orientere seg rundt de små eruptive felter.

Ser man nu Kongsberg—Bambleformasjonen som et utsnitt av et stort erupsjonsområde, således som jeg her har beskrevet det, og vil i overensstemmelse med Th. Vogt søke å parallellisere den med tilsvarende bergarter i Sverige, er jeg enig med Vogt i, at den til en viss grad kan innpasses i Magnussons svioniske cyklus, således at:

1. båndgneisene svarer til Leptittformasjonenes bergarter,
2. diorittene svarer til urgranittene,
3. gabbroene (olivinhyperittene, vinordiabasene og de yngre amfibolitter) svarer til grønstenene, og
4. granitten svarer til Fellingsbro Stockholms-gruppens granitter.

Som en påfallende forskjell mellom de to cykler vil man bemerke, at de orogenetiske bevegelser i Mellomsverige har vært kraftigere enn i Norge. Foldningene og omvandlingene i forbindelse med urgranittenes framtrengen har vært mer gjennomgripende enn ved de diorittiske bergarters framtrengen i Kongsberg—Bamble-formasjonen og en parallell til den metamorfose, som i Sverige gikk forut for Fellingsbro Stockholms-granittens framtrengen og ledet til dannelsen av Sørmlands-gneisen mangler helt i Kongsberg—Bamble-formasjonen.

Ser man på Kongsberg—Bamble-formasjonens forhold til de gneisformasjoner som omgir den mot øst og vest, vil man bemerke, at den er helt uberørt av den orogenese, som i den gotiske cyklus ledet til forgneising av det sydvestlige Sveriges og sydøstlige Norges grunnfjell og den er heller ikke berørt av den orogenese og migmatisering, som har omdannet store områder av Telemark-formasjonens bergarter mot vest.


Boknfjorden
„Telemarksformasjonens gneisgranitter" med suprakrustalområder.
breccie
Kongsberg-Bamble formasjonen.
breccie
Oslofeltet
„Sydvest-svenske gneis" med suprakrustalområder.
Filipstad-granitten.
Leptittformasjonen
Stockholm

I likhet med Th. Vogt finner jeg det naturlig å henføre Telemark-formasjonen med dens gneiser, granitter og suprakruslatområder til Magnussons gotiske cyklus. Således som ovenstående profil viser. Ut fra en sådan synsmåte står man foran å forklare det eiendommelige faktum at Kongsberg—Bamble-formasjonen ikke alene er uberørt av den Sørmlandske forgneising i den svioniske cyklus, men at den også med skarpe grenser ligger innklemt som en kile i det store syd-skandinaviske gneisområde, som har fått sin forgneising i den gotiske cyklus.

Migmatiseringen i den sydvestlige del av Telemark-formasjonen er som Tom. Barth har beskrevet det regional. Østover mot de store forkastningsbreksjer mellom Kongsberg og Gjøvik kommer man jevnt op i nivåer av Telemark-formasjonen, som må ha ligget nærmere dagen. Man finner der foldede og pressede bergarter, men mindre migmatisering.

Ved sydenden av Sperillen avsluttes den store rivningsbreksje ved Flå-granitten og kun kvartsbreksjen fortsetter inn i dette granittmassiv på samme måte som det er beskrevet ved breksjens gjennomskjæring av Birkeland-granitten.

Efter et hopp mot øst finner man atter rivningsbreksjen fra Onsberget og Brandbu ved Randsfjorden til Gjøvik. Jeg har ennu ikke hatt anledning til inngående å studere forholdene her ved breksjens nordlige avslutning. Under et par dages ekskursjon høsten 1941 fikk jeg anledning til å gå op et profil langs landeveien på Mjøsas østside hvortil Magnusson har fulgt den „Värmlandske mylonittsonen". Vest for Mjøsa kunde sonen følges nord—vestover gjennom Toten til henimot Einavatn. Lenger vest enn til den store rivningsbreksje kan mylonittsonen ikke følges. Vest for rivningsbreksjen finner man kun de vanlige Telemark-granitt-typer med nordøstlig strøkretning. Øst for rivningsbreksjen Brandbu—Gjøvik kommer man altså atter over i dypere nivåer av en forgneisingssone. Man har der mylonittgneiser, men ikke virkelige migmatitter som man finner i det sydvestlige Norge.

Det er sannsynlig, at gneisene øst for rivningsbreksjen tilhører samme gneisområde som gneisene vestenfor. Men at man på østsiden har gneiser fra et dypere nivå, som er skjøvet op i høide med de mindre omvandlede Telemark-gneiser.

Samtidig med opskyvingen av de østlige mylonittgneiser er det sannsynlig, at den av de orogenetiske bevegelser uberørte Kongsberg—Bamble-formasjon er kilt inn fra fjernere liggende trakter, hvor den har vært uberørt både av den svioniske og den gotiske forgneising.

Ved innkilingen av Kongsberg—Bamble-formasjonen måtte de sydlige deler av gneisområdene fjernes fra hinannen. Dette stemmer godt med de nordøstlige og nordvestlige strøkretninger som karakteriserer gneisene, henholdsvis vest øst og for Kongsberg—Bamble-formasjonens nordlige del.

Nesten flattliggende dype glidestriper, som ofte sees på glideflater i rivningsbreksjen og i parallellbreksjer i Kongsberg-formasjonen støtter opfatningen om en innskjøvet Kongsberg—Bamble-formasjon, da de viser at store horisontale forskyvinger virkelig har funnet sted.

Efter at Kongsberg—Bamble-formasjonen er bragt på sin nuværende plass, har Flå-granitten og Birkeland-granitten trengt fram og har brutt den gamle rivningsbreksje.

Efter at disse granittene er størknet, er de atter brutt op ved en senere bevegelse langs breksjen og er sammenbundet av gjennomflettende kvarts i ganger og årer. Ved denne siste opbrytning er bruddstykkene ikle mylonittiserte som i rivningsbreksjen og der har kun foregått forkhodsvis ubetydelige glidninger.

Hvis man regner Telemark-gneisen til den gotiske cyklus, kan Flågranitten og Birkeland-granitten innpasses sammen med Bohus-granitten og Karlshamn-granitten som de siste granittinjeksjoner ved orogenesens avslutning.

I mitt foredrag gav jeg også en kort orientering over geologien ved Knaben gruver og på et kart viste jeg også hvorledes dalene vestover fra breksjen er forholdsvis lite utpreget sålenge migmatitten vedvarer (altså til Undal). Lengre mot vest er granitten nesten enerådende og dalene er dypt nedskåret mellom høge fjell. Da det er min hensikt å utføre en mer inngående beskrivelse av molybdenforekomstene, medtar jeg her intet referat av denne del av mitt foredrag, men har i det foregående gitt et noget utvidet referat av den del av foredraget som omfattet Kongsberg—Bamble-formasjonen. Jeg fant det av interesse i forbindelse med min oversikt over Bamble-formasjonen å vise fram grubekarter fra Knaben, som viser en stadig skiften mellom yngre aplittisk granitt, pegmatitt og kvartsmasser som — omenn i mindre målestokk — minner om aplittene, pegmatittene og kvartspegmatittene i Bamble-formasjonen.

I ordskiftet etter foredraget deltok formannen, J. Bugge, C. Bugge, T. Barth, Th. Vogt, F. Isachsen, S. Foslie, V. Goldschmidt og foredragsholderen.

Ved aftensbordet var det taler av formannen for samholdet mellom de norske geologer, av Rosendahl om Henrich Steffens og hans planer for geologisk utforsking av Norge, av N. H. Kolderup, som innbød til det neste landsmøte i Bergen, dessuten av Holtedahl, Brækken, Carstens, Vogt og Münster Strøm. Ved kaffen leste Braastad Mikjel Fønhus' dikt om Spitsbergen.

Ms. mott. 6. nov. 1941

OLAF ANDERSEN

Minnetale i Norsk geologisk forening 6. november 1941

AV

ARNE BUGGE

Olaf Andersen blev født på Hønefoss 12. mars 1884. 1911 blev han cand. real. med geologi som hovedfag. Hans hovedfagsopgave er en meget omhyggelig utført beskrivelse av de ved Notodden forekommende epidot—kalkspat-ganger som er publisert i Archiv for Math. og Naturv.

Som student vikarierte Andersen som amanuensis ved Mineralogisk Institutt mens Schetelig var på en studiereise.

Da han var ferdig med studiene, reiste han til Amerika hvor han studerte geologi ved Columbia University i New York inntil han i mars 1912 blev ansatt ved Geophysical Laboratory ved Carnegie Institution of Washington. Ved dette velutrustede laboratorium fant han arbeidsvilkår som passet ham, og han levet her noen lykkelige og produktive arbeidsår inntil han i 1918 blev kalt til å organisere og senere lede Råstoffkomitéens laboratorium for ildfaste materialer. Samtidig blev han også utnevnt til statsgeolog.

De første 3 år av Andersens arbeide ved Carnegie-instituttets laboratorium var preget av et intenst eksperiment-arbeide samt publisering av resultatene. Han publiserte først en avhandling om magnesium- og mangan pyrofosfatenes krystallografiske og optiske egenskaper. I 1914 publiserte Andersen sammen med N. L. Bowen resultatene av de epokegjørende eksperimenter vedrørende krystallisasjons-processen i systemet magnesiumoxyd—siliciumdioxyd. For eruptivbergartenes petrologi fikk disse eksperimenter enorm betydning; de har vært bestemmende for denne vitenskaps videre utvikling gjennom hele mellomkrigstiden. Enhver petrograf er nu fortrolig med dette system, hvor reaksjonsprincippet for første gang blev demonstrert i mineralogiske smelter: Under visse forutsetninger vil den tidlig dannede olivin (forsterit) reagere med smelten og isotermt omdannes til pyroxen (enstatit).

Hver for seg foretok derpå Andersen og Bowen eksperimenter med krystallisasjon i systemene: diopsid—forsterit—kiselsyre, og anorthit—forsterit—kiselsyre. Resultatene av eksperimentene med det førstnevnte system blev publisert av Bowen 1914, og resultatene av eksperimentene med systemet anorthit—forsterit—kiselsyre publiserte Andersen i 1915. Han påviste da, at den forsterit som utkrystalliserer også i dette system vil kunne reagere med smelten og omdannes til enstatit, og sluttet derav at denne reaksjon jevnlig foregår under krystallisasjon og størkning av naturlige gabbroide magmamasser. Herved var en ny veg åpnet til forståelse av den magmatiske differentiasjon, en veg som førte like inn i hjertet av det fundamentale problem i vår vitenskap, problemet om bergartenes oprinnelse.

Desverre fikk ikke Andersen anledning til å forfølge disse studier videre: Amerika fikk bruk for ham i sin krigsproduksjon under forrige krig, og senere kom Andersen til Norge hvor midlene til hans forskning manglet. Men han hadde rukket å være med som grunnlegger av de nye ideer, og han hadde gleden av å se hvordan hans ideer, i andre forskeres tjeneste, brøt igjennom og skapte en ny petrologisk vitenskap.

I 1915 publiserte Andersen en avhandling hvor han framla sine eksperimenter med schilleriserende feltspat. For første gang blev der framlagt en på eksperimenter grunnlagt forklaring av schilleriseringen som følge av tynne jernglansbelegg på feltspatens spalteflater.

De siste 3 år ved Carnegie-instituttet var viet arbeider i forbindelse med den industrielle ekspansjon under krigen.

Da Andersen skulde overta sitt arbeide med å organisere Råstoffkomitéens laboratorium for ildfaste materialer, satte nedgangstiden efter krigen inn, og han rakk kun delvis her å få utnyttet sine rike erfaringer før arbeidet måtte stilles i bero.

Våren og sommeren 1919 var han atter i Amerika for å studere forskningsinstitutter i U. S. A. og Canada.

Erfaringene fra denne reise er publisert i en artikkel i Teknisk ukeblad om Melloninstituttet i Pitsburg og i Tidskrift for kemi som et referat av et foredrag han holdt i »Centralkomitéen for vitenskapelig samarbeide til fremme av næringslivet«.

Han gjennemgår i disse artikler de forskjellige forskningsmetoder som kommer til anvendelse i Amerika og anbefaler som passende for Norge Melloninstituttets system med stipendiatavdelinger ved de vitenskapelige undervisningsanstalter, og ennvidere det system som Mines Branch i Canada har, med dens laboratorier og forskningsstasjoner underlagt en central administrasjon i hovedstaden. —

I foredrag i Geologisk forening 1920 og i Råstoffkomitéens publikasjon nr. 1 gav han en oversikt over de resultater man har opnådd henholdsvis i studiet av optisk glas og de ildfaste oksyders fysikalske kjemi.

I Råstoffkomitéens serie i N. G. U.s skrifter utgav han videre en avhandling om en kvartsforekomst i Krødsherad og sammen med Holtedahl en beskrivelse av norske dolomittforekomster med et tillegg om dolomittens anvendelse.

Hans hovedarbeide som statsgeolog blev hans avhandlinger om feltspat og pegmatittganger, som er publisert i Norges geologiske undersøkelses skrifter og i Norsk geologisk tidsskrift. Hans feltspatarbeider har spillet en stor rolle for den praktiske utnyttelse av rene feltspatforekomster og står som et mønster på en beskrivelse av en av de mange grupper nyttige mineraler som finnes i vårt land.

For hans arbeider om feltspat fra granitt-pegmatitter som er trykt i Norsk geologisk tidsskrift, blev han 1930 tildelt Reusch-medaljen.

I begrunnelsen ble det framhevet at han ved dette arbeide var nådd et langt skritt fram til forståelse av perthittdannelsen. Særlig framhevedes hans overbevisende tolkning av den primære perthittdannelse og den sekundære i forbindelse med rekrystallisasjon, resorbsjon og fortrengning (replacement). Som statsgeolog foretok Andersen kartlegging av et område omkring Flågranitten. Ennvidere kartla han en betydelig del av kystområdet på Arendal rektangelblad. Andersen vilde gjerne fortsatt sitt virke i Norge, men han fant ikke de økonomiske arbeidsvilkår som han trengte. Som 25års-jubilant skrev han i 1926 i sin levnetsbeskrivelse at han anså Norges geologiske undersøkelse som en ønske-institusjon å arbeide ved, hvis bare de administrative og bevilgende statsmakter vilde utføre noen enkle regnestykker vedrørende de midler som trenges for å undersøke et vidstrakt land.

Da han ikke fant de rummelige arbeidsvilkår som han trengte, mottok han 1928 et tilbud fra United Steel Corporation, og blev avdelingsleder ved denne institutions forskningslaboratorium. Samtidig utnevntes han til professor ved Stevens Institute of Technology i New York.

Ved det for private midler drevne forskningslaboratorium kunde han bare i liten grad publisere sine forskningsresultater. Fra hans siste arbeidstid i Amerika fra 1928 til hans død 18. juli 1941 foreligger derfor kun 2 publikasjoner fra dette arbeidsfelt: En avhandling om den mineraldannelse som der under en smelteovns drift framkommer i ovnens magnesiaforing, og sammen med dr. Harley Lee en beskrivelse av tri-calsiumsilikatets egenskaper i basisk slagg fra stålsmeltning.

I denne forening vil vi minnes Andersen som et medlem der alltid ydet bidrag fra sitt rike kunnskapsforråd. Vi minnes ham særlig som foreningens formann i 1923 og for hans arbeide med å sette i system den vitenskapelige belønning som foreningen utdeler i form av Reuschmedaljen.

De som har hatt den lykke å lære Andersen personlig å kjenne, minnes ham som den virkelige vitenskapsmann. Sannhetssøkeren som søker sannheten kun for sannhetens skyld. Alltid var han rede til å gi andre del i sine rike kunnskaper og det var ham en glede å vite at hans mange forbindelser ikke *bare* var hans egne forbindelser. Han var alltid rede til å dele dem med sine landsmenn når de kom til Amerika, og der lyste en glede i hans øine når han forstod at han hadde brakt en av sine landsmenn i kontakt med en som kunne være til nytte i arbeidet.

Han fikk gode arbeidsforhold i sitt nye land og han var tilfreds i sin familiekrets der, men han hadde gitt for meget av sitt liv til arbeidet i Norge og han følte en dragning tilbake til skog og skjærgård som vel aldrig forlot ham.

Arne Bugge.

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ON THE SPECTROCHEMICAL DETERMINATION OF VANADIUM IN IRON ORES AND SLAGS

BY

ASLAK KVALHEIM

WITH 7 FIGURES IN THE TEXT

Introduction.

It is a wellknown thing in spectrography, that if one is making quantitative determinations of some chemical element in one sort of material, and then turns to determine this element after the same method in another material, having a base substanse essentially different from the first, a trial of the validity of the calibration curve for the new material (the new base) is necessary, often with the result that a new calibration curve must be constructed. In the most favourable case the calibration curves constructed for different bases, are identical or nearly identical, but as a rule one must be prepared to find the curve displaced, because the intensities of the spectral lines applied, may be influenced by the physical conditions prevailing in the arc, and by the manner in which the elements evaporate from different base substances, and these conditions may vary when the dominating substanse is e. g. lime, silicates, or metals.

This displacement of the calibration curve may in some cases be of a considerable magnitude, and may necessitate a careful and critical treatment of the analysis results. So L. W. Strock (1) found that the sensitivity of Li is five times higher in a 1 : 1 mixture $NaCl : SiO_2$ than in pure quartz.

It may often be advantageous to stabilize the arc temperature by adding e. g. NaCl, albite, SiO_2 or other compounds to the samples in such quantities that these dominate the base substance, or it may be possible to find spectral lines or line pairs, the relative intensities of which are only to a small degree modified by changes in electrical discharge conditions.

The author has often had the opportunity of observing certain irregularities which occur by spectral analyses of vanadium in the arc. These irregularities became especially evident during the composing of methods for spectrographical determination of vanadium, titanium, and other elements in iron ores, and of vanadium in slags, and as the deviations were found to be of a considerable magnitude, the present investigation was started in order to make an attempt to find which components of the base substance are responsible for the deviations, how they influence the intensities of the spectral lines used, and if possible, find a method which reduces the deviations to a minimum.

The Determination of V in Iron Ores Using Fe as a Comparison Element.

By the composing of the spectrographic method for the determination of V in iron ores, 5 magnetites served as standards. According to chemical analyses* these magnetites contained:

		% V	% Ti	% Fe
Concentrates	Magnetite A	1.17	6.90	57.8
	» B	0.83	2.70	64.8
	» C	0.50	1.80	65.0
Crude Ores	» D	0.17		21.34
	» E	0.23	3.18	35.45

In addition to these I have also used the iron ores B and C diluted 1 : 1 with pure Fe_2O_3.

Now a quantitative spectral analysis can be carried out in many ways, but it is best to compare a spectral line of the element to be determined, with a suitable line of an element occurring in known and large (easily determinable) quantities in the material which is examined, or with a line of an element which is added to all the samples in a definite and so large amount, that traces of this element previously present in the substance to be analysed, do not disturb the analysis.

As to the iron ores, it therefore seems natural and convenient to compare the intensity of a V-line with that of a Fe-line; then a chemical determination of Fe is a fairly easy matter, and especially since from a spectrographical point of view, there seems to be few objections to make against a line-pair V—Fe. Both elements vaporise at about the same rate from the arc, they both have so many lines, that it should not be difficult to find a V-line with a neighbouring Fe-line, both lines being free from disturbing coincidences and having comparable intensities at the V- and Fe-concentrations concerned.

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* It may be mentioned here that unintelligible difficulties and wasted work at the beginning, turned out to be due to essentially incorrect V- and Fe-figures, which had been reported according to industrial chemical analyses. E. g. the ore D was reported to contain 0.28% V and 35.0% Fe. The correct figures then have been determined by conservator, engineer K. Kristoffersen.

Everything taken into consideration, a determination of V with Fe as a comparison element seemed to be promising and convenient, and consequently a method was prepared for this determination. It is necessary here to describe the method shortly, and especially the construction of the calibration curve from the blackening curves of the V- and Fe-lines.

Method: Among the many V- and Fe-lines 2 line pairs were chosen as well suited for the analysis, namely V I 3185.396 — Fe I 3205.400 and V I 3056.334 — Fe I 3055,263. V 3185 coincides with the weak Ca-line 3185, but this does not disturb the analysis except when the Ca-content is high and the V-line at the same time very weak. When the V-content is as high as in the standard magnetites, this coincidence is of little importance, even if the magnetites are diluted 1:10 with $CaCO_3$.

Other serious coincidences are not present, except Mo 3055.323, when the samples contain Mo.

The spectrograph used was a large quartz spectrograph constructed by R. Mannkopff in Göttingen. It had a dispersion corresponding to 6.5—7.5 Ångstrom pr. mm on the plates in the region used. The powdered sample, mixed with two parts by weight of carbon powder to get a steady and quiet arc, was packed into a bore 4 mm deep and of 1.5 mm diameter in a pure carbon cathode of 3 mm diameter. The anode carbon had a diameter of 4 mm. After the arc was started, it burned for 3 minutes at a current of 6.5 amps. The method for making the spectra was the one described by L. W. Strock (2), by which the spectra are stepped so as to serve as their own density calibration marks. The ²/₃ of the arc nearest to the cathode was projected diffusely on the spectrograph slit, and by rotating a step sector just before the slit, a stepped spectrum was produced. The different steps along each spectral line were thus given exposure times which were in the ratio 1:2:4:8:16:32:64. The spectra were photographed on Perutz graphic plates, which were developed in a Metol Hydroquinone developer.

By means of a recording michrophotometer several steps of the selected V- and Fe-lines were photometered. The photometer curves thus achieved, can be used for quantitative analysis after several methods, but here was chosen the method of constructing the blackening curves as this method is the most reliable and accurate.

The blackenings of different steps of the V-and Fe-lines respectively, is calculated from the galvanometer deflections from the equation:

$$S = \log \frac{I_0}{I}$$

where I_0 is taken as the galvanometer deflection for an unexposed part of the plate, and I is the deflection produced by the line whose blackening is to be measured.

The blackening curve of a line shows the relation between the density of blackening of this line on the plate, and the intensity of illumination which produced the line.

Fig. 1 shows an example of the blackening curves of the line pair V 3185 and Fe 3205. The curves show the relation between blackening S and log relative exposure time, (instead of log relative intensity) since a step sector has been employed (3).

When a spectral line increases in intensity, its blackening curve will move to the left, and since the intensity of a line increases with the percentage of the element concerned, the horizontal distance between the blackening curves of the V- and Fe-lines (Δ log T) is dependent of the concentration ratio V:Fe.

This horizontal difference Δ log T, which is here measured in mm (10 mm = log rel. exposure time 0.3) is zero when the V- and Fe-lines are of the same intensity, it is positive when the V-line is the stronger, and negative when the V-line is of less intensity than the comparison line of Fe.

The calibration curve is constructed by plotting Δ log T in mm against log concentration ratio V:Fe. On fig. 2 the calibration curves for the line pairs V 3285—Fe 3205 and V 3056—Fe 3055 are shown.

Such curves are usually linear over wide intervals, and the determination of V is carried out thus: The spectra of the samples to be analysed are photographed as described above, the selected lines of V and Fe are photometered and the blackening curves constructed. Then the distance Δ log T between the linear parts of these curves is measured (Δ log T was measured in mm at the blackening

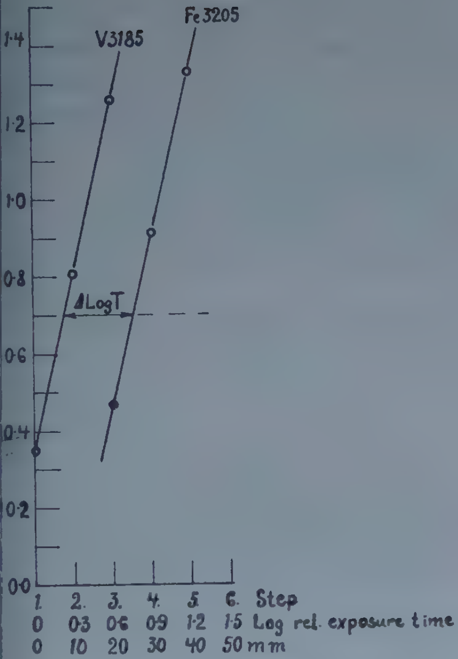

Fig. 1. Blackening curves.

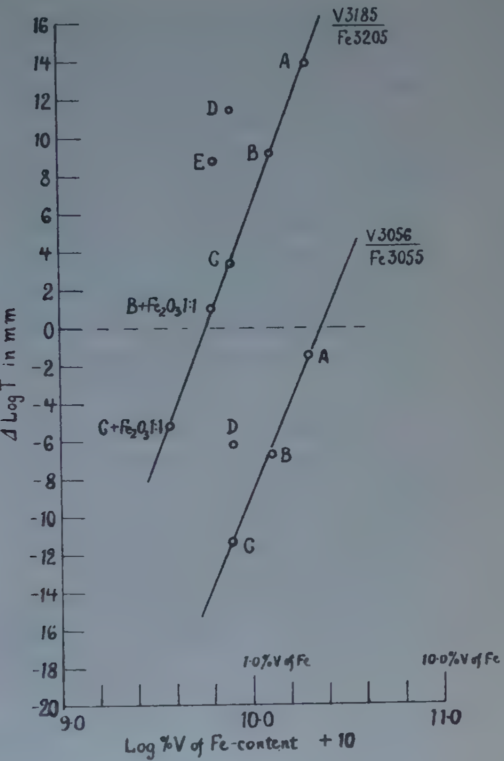

Fig. 2. Calibration curves.

s = 0.7), and the concentration ratio V : Fe can be read from the calibration curve.

It is seen on fig. 2 that the curves ABC must be considered as good calibration curves, they are as straight as can be expected when one remembers that those curves are founded om chemical analyses of the standards, whereby uncertainties from the chemical determination are also brought in.

But the points D and E do not seem to belong to the calibration curves at all, as a determination of V by means of the curves ABC using e. g. the line pair V 3185—Fe 3205 would give a V content more than 100 relative % too high, and this is an irregularity that by far exceeds the usual deviation of ± 10%, and brings into the analyses a dangerous element of uncertainty.

This irregularity was one of the causes of this investigation.

The problem first arising was this:

Why do the points D and E fall far outside the curve ABC, and how can reliable spectrochemical analyses of V in iron ores be carried out, and spectrochemical analyses of V in general?

Now the ores D and E are of a chemical combination different from A, B, and C, because A, B, and C are iron ore concentrates, while D and E are crude ores containing at least 50% of silicate rock, and consequently it can at once be seen that to use the calibration curve ABC for these unconcentrated ores is in disagreement with the general rules for quantitative spectrum analyses, because to ensure good results one must take care that the samples to be analysed and the standard mixtures have approximately the same base substance.

Deviations of this sort caused by differences in the base substance are familiar things often met with in spectrochemical work. L. W. Strock (1) has shown the effect which additions of $CaCO_3$, NaCl, and SiO_2 to the samples have upon the intensity ratios $\frac{\text{Li } 6707.86}{\text{Sr } 6408.48}$ and $\frac{\text{Li } 6103.59}{\text{Sr } 6408.48}$ pointing out that an addition of NaCl gives rise to the intensity of the Li-lines applied, while the intensity decreases when $CaCO_3$ is added. And W. Rollwagen (4) has shown how the influence of different base substances upon the intensities of spectral lines can be explained by variations in the physical conditions e. g. temperature of the arc, caused by these bases.*

The deviations mentioned are in many cases small in spite of considerable difference in the composition of the materials analysed, and it is therefore often unnecessary to construct new calibration curves.

The ideal solution of the problem will of course be to find line pairs the intensity ratios of which are not at all influenced by variations in the base substance, i. e. by variations in the conditions prevailing in the arc (5). But such a line pair is not always easily found, and in practice one must usually be content with less ideal line pairs.

Considering the iron ores D and E the deviations are great, and as those deviations are very likely to be traced to the accompanying rock, it would be of interest to investigate the influence of other materials upon the V-determinations. At my disposal were several slags with known V- and Fe-content according to chemical analyses, and these slags were used as standards in the same vay as the iron ores. The result was deviations from the iron ore calibration curve far exceeding those found for D and E, the analyses of the slags giving V-contents 6½ times too high, when the line pair V 3185—Fe 3205 was employed, and about 3½ times too high when the line pair V 3056—Fe 3055 was used.

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* See also R. Mannkopff Zeits. f. Physik. *86*, 183, 1933.

This shows that the intensity ratios $\frac{\text{V } 3185}{\text{Fe } 3205}$ and $\frac{\text{V } 3056}{\text{Fe } 3055}$ are very sensitive against variations in the base substance, but the intensity ratio $\frac{\text{V } 3055}{\text{Fe } 3056}$ is less influenced than the ratio $\frac{\text{V } 3185}{\text{Fe } 3205}$.

As the deviations of D and E from the iron ore calibration curve ABC, are supposed to be due to the silicate rock which those unconcentrated ores contain, a mixture of D with one of the concentrates e. g. A, must also give an intensity ratio $\frac{\text{V}}{\text{Fe}}$ deviating from the curve ABC. That this is really the fact, table 1 shows quite clearly, the deviations increasing with increasing addition of D to the mixture, the deviation of D forming the limit.

Table. 1.

Substance examined	$\frac{\text{V}}{\text{Fe}}$ in per cent	Line pair V 3185—Fe 3205			Line pair V 3056—Fe 3055		
		Δ log T calculated (mm)	Δ log T found (mm)	Rise in Δ log T (mm)	Δ log T calculated (mm)	Δ log T found (mm)	Rise in Δ log T (mm)
D alone	0.80	+ 3.2	+ 11.5	8.3	—11.2	—6.2	5.0
80 % D + 20 % A	1.30	+ 8.8	+ 15.9	7.1	— 6.1	—1.9	4.2
60 % D + 40 % A	1.59	+ 11.2	+ 17.2	6.0	— 4.0	—0.2	3.8

For a closer examination D and E were subjected to a magnetic separation. In the magnetic parts (magnetite) V was determined by means of the calibration curve ABC, while the influence of the unmagnetic parts upon the V-determination were tested by mixing 7 parts by weight of these silicates with 3 parts of the concentrate C, thus producing a mixture corresponding to D.

If the rock content is the cause of increase in the intensity ratio $\frac{V}{Fe}$ as to D and E, this rock must have a similar influence when added to the concentrate C.

Table 2 confirms this presumption. The change in Δ log T is of about the same magnitude when the silicates are added to C, as when added to the magnetic concentrates of D and E. (That the change in Δ log T is not ca. 8 mm corresponding to the deviation of D and E from the calibration curve ABC, is explained by the fact that the silicate rock itself contains a considerable amount of Fe.)

Table 2.

Substance examined	Δ log T in mm V 3185—Fe 3205		Rise in Δ log T (mm)
	Concentrate alone	30 % concentrate + 70 D % unmagnetic	
Magnetic concentrate of D	+ 8.0	+ 11.5	3.5
C	+ 3.3	+ 7.9	4.6
		30 % concentrate + 70 % E unmagnetic	
Magnetic concentrate of E	+ 4.0	+ 8.7	4.7
C.............................	+ 3.3	+ 7.8	4.5

Thus it is proved that the irregularities which occur in the spectrochemical examination of D and E, are caused by the influence of the silicates contained in those unconcentrated ores. These silicates give to the intensity ratio $\frac{V}{Fe}$ a rise (increase in Δ log T) which renders the calibration curve ABC inapplicable to unconcentrated ores still containing rock minerals.

As the rock consists of several components it will be of interest to find out if the increase in Δ log T is due to one single component or to a combination of more of them.

A microscopic examination of the unmagnetic parts of D and E, which Professor Dr. V. M. Goldschmidt was so kind to carry out for me, showed that the unmagnetic rock was composed thus:

Chief component: Hornblende (green amphibole); next: a feldspar of the plagioclase group; subordinately: brown biotite.

In addition to this, the sample contained still a little iron ore, probably ilmenite, a little corundum, and a little garnet. The samples derived from D and E were obviously different, but the difference was not so great as to involve any serious difference in chemical composition.

According to chemical analysis the unconcentrated iron ore E contained:

Fe	35.45	per	cent
V	0.23	»	»
TiO_2	5.30	»	»
SiO_2	23.00	»	»
Al_2O_8	9.89	»	»
MgO	5.65	»	»
CaO	4.26	»	»

The cause of the increase in Δ log T must be found in one or more of the chemical components above, given in the table besides Fe and V, or in a combination of several of these components. Of these TiO_2 can at once be excluded, because D and E do not essentially differ from the other ores in Ti-content, and as A contains even 11.5 per cent of TiO_2 without being influenced by this percentage in any way.

The remaining components to be investigated are SiO_2, Al_2O_8, MgO and CaO, and the influence of these components upon the intensity ratio $\frac{V}{Fe}$ were tested one by one, by mixing the magnetite C with each of these components in several concentrations. SiO_2 showed no effect, MgO showed little influence, while Al_2O_8 influenced the intensity ratio considerably and CaO had the greatest effect. Ca added in the form of $CaCO_3$ showed the same effect as when added in the form of CaO.

Fig. 3 shows how the horizontal distance (Δ log T) between the blackening curves of V 3185 and Fe 3205 varies with the added amounts of the more or less active components, the ratio $\frac{\text{percentage of V}}{\text{percentage of Fe}}$ being kept constant all the while.

Assuming that each chemical component of the rock acts as if it were alone, one can calculate the total effect of the umagnetic part of E (58 per cent), by adding up the partial effects of SiO_2, MgO, Al_2O_8 and CaO.

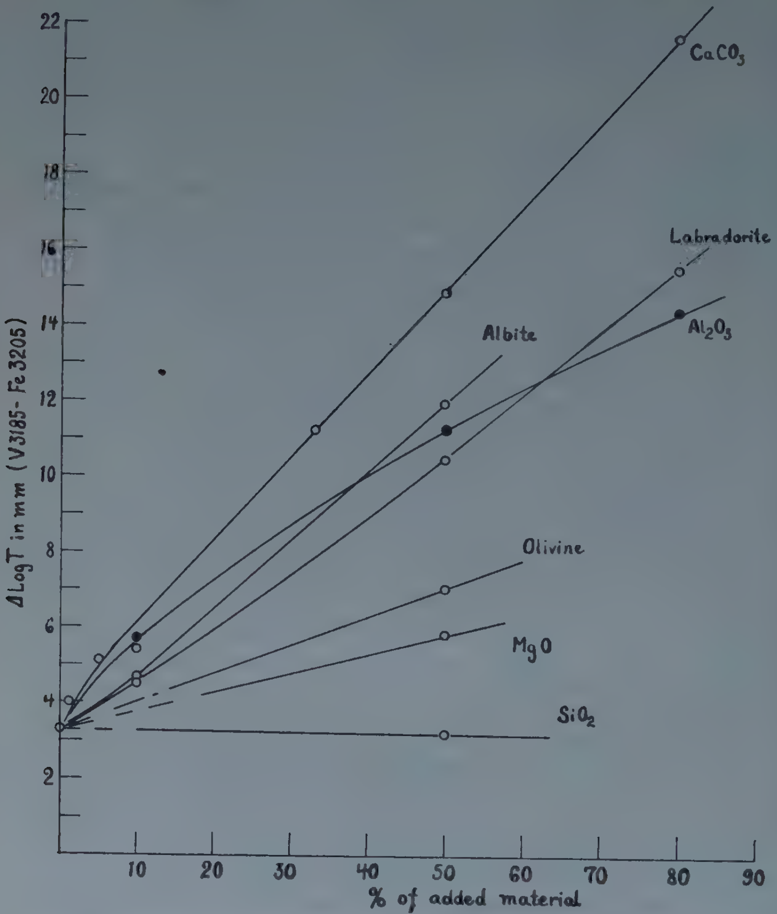

Fig. 3. Influence of $CaCO_3$-, SiO_2-, Al_2O_3-, MgO-, olivine-, albite-, and labradorite-content on blackening curve separation V3185—Fe 3205.

$$\frac{\%V}{\%Fe} = \text{const.} = 0.0077.$$

The total increase of Δ log T (deviation of Δ log T from the calibration curve ABC) for the iron ore E would then be: —0.1 (SiO_2) + 0.3 (MgO) + 2.4 (Al_2O_8) + 2.3 (CaO) = 4.9 mm. But this is less than 2/3 of the real deviation of 7.6 mm which was found by experiment.

This shows that the change in Δ log T can not be explained merely as a sum of the partial effects of the different chemical components, and there is only one solution possible: The deviations are caused by one or more combinations of these chemical components, and as the chief compounds of the rock concerned are hornblende and feldspar, these must give the solution.

Accordingly a hornblende—feldspar mixture that is added to the iron ore concentrates must produce the effect that the intensity of the V-lines used are increased as compared with that of the Fe-lines, and the deviation from the calibration curve ABC thus found must be in agreement not only qualitatively but also quantitatively with the deviation which D and E show.

The adding of a hornblende—feldspar mixture involves however the disadvantage that the hornblende would bring some Fe into the mixture, and to avoid this, a mixture in composition corresponding approximately to the silicates in D and E were made by thorougly mixing

1 part by weight of olivine
1 » » » » albite and
2 parts » » » labradorite.

The Fe-content of this mixture is so small (1.2% Fe) that it does not seriously influence the analysis.

This olivine—albite—labradorite mixture was added to the concentrates A, B, and C in the proportion, 1 part of mixture to 1 part of the concentrate, carbon powder was added as usual, and of the standards thus prepared spectra were taken in the same way as all the previous spectra. The result was the calibration curves II seen on fig. 4 a and b.

The deviations agree with the deviations from the iron ore calibration curves produced by D and E. D containing 58 per cent of rock falls practically on the curves, while E which contains about 70 per cent of rock falls a little to the left, which is to be expected as the curves are constructed for iron ores containing 50 per cent of rock.

But how does each of the components olivine, albite and labradorite influence the intensity ratio $\frac{V}{Fe}$? How much of the change in Δ log T is due to the olivine, and how much to the albite and labradorite?

Fig. 3 shows the influence of these components upon the blackening curve separation Δ log T of the lines V 3185 and Fe 3205,

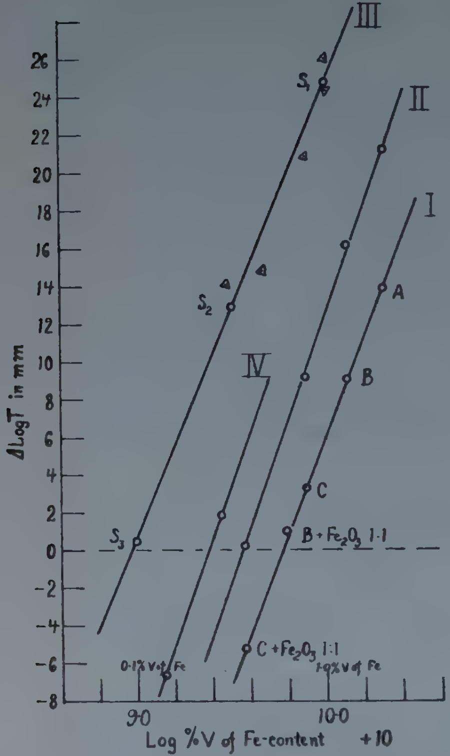

Fig. 4 a. Calibration curves for the line pair V 3185—Fe 3205.

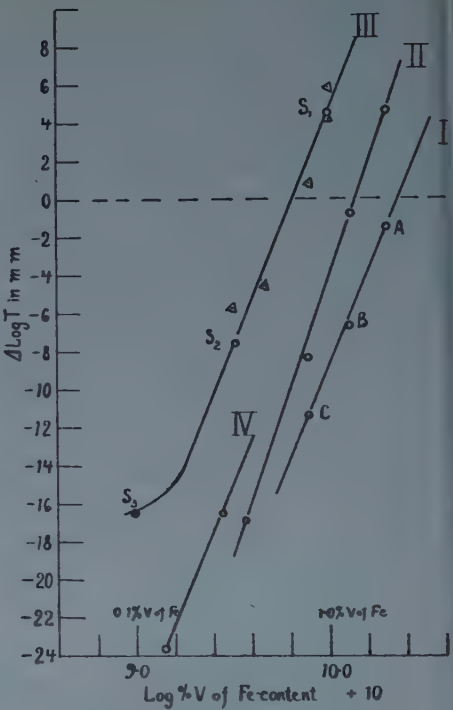

Fig. 4 b. Calibration curves for the line pair V 3056—Fe 3055.

when each of these components are added to the concentrate C. By summing up the partial effects of olivine, albite, and labradorite, the total change in Δ log T, related to the above mixture (1 part of olivine, 1 part of albite, 2 parts of labradorite, and 4 parts of C) is calculated to:

0.9 (12.5% of olivine) + 1.8 (12.5% of albite) + 3.4 (25% of labrador) = 6.1 mm, while the change in Δ log T as measured in fig. 4 a is found to be 6.2 mm. The agreement is complete.

Interesting in this connection is the fact that albite and labradorite show about the same effect in spite of their different chemical composition (albite containing about 12 per cent Na_2O and no CaO, and labradorite containing 14 per cent CaO and about 3 per cent Na_2O). In agreement with this the substitution of labradorite for albite in the above mixtures did not change the result.

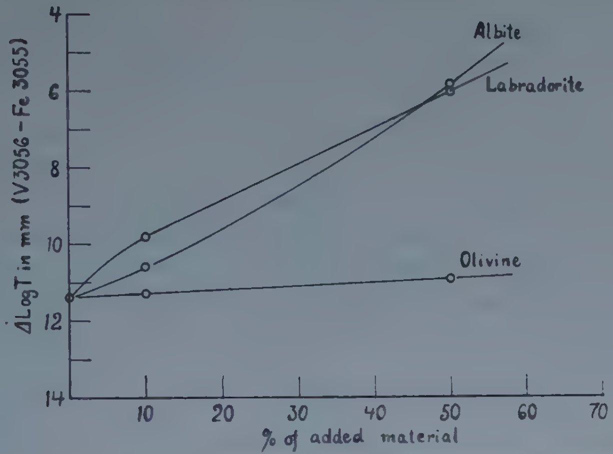

Fig. 5. Influence of olivine-, albite and labradorite-content on blackening curve separation V 3185—Fe 3205.

$$\frac{\%\ \mathrm{V}}{\%\ \mathrm{Fe}} = \mathrm{const.}$$

In order to find out if the change in Δ log T which the other line pair V 3056—Fe 3055 exhibits could be explained in the same way as shown above for the lines V 3185 and Fe 3205, the curves in fig. 5 were constructed. These curves show the influence of olivine, albite, and labradorite upon the blackening curve separation Δ log T of the line pair V 3056—Fe 3055. By adding up the partial effects of olivine, albite and labradorite, the change in Δ log T is calculated to: $0.1 + 1.1 + 3.0 = 4.2$ mm. The change measured in fig. 4 b is 4.0 mm.

Here may perhaps also be mentioned some interesting features which the influence of NaCl exhibits, as NaCl might be expected to produce a similar effect as albite.

The concentrate C was diluted 1 : 19 and 1 : 1 with NaCl. To the 1 : 1 mixture 2 parts of carbon powder were added as usual, to obtain a steady and quiet arc, while the 1 : 19 mixture produced a quiet arc without this addition. The spectra of these mixtures when taken in the ordinary way, showed that NaCl had no influence upon the intensity ratio $\frac{\mathrm{V}}{\mathrm{Fe}}$, as Δ log T was found to be of the same magnitude as for the concentrate alone.

But when spectra were taken in successive fractions of 1 minute each, some characteristic features became visible. The fractionated exposures showed quite clearly:

1. that the V I-lines 3185—83, 3060, and 3056 increase considerably in intensity as compared with the V II-lines 3125, 3118, 3111, and 3102 when NaCl is added. When NaCl at the end of the first minute has disappeared from the arc by fractional evaporation, this effect disappears too.

2. V and Fe do not evaporate simultaneously and at the same rate, when NaCl is added, as V to a great extent evaporates at the same time as Na, while most part of the Fe remains in the carbon until Na has disappeared. The amount of V evaporating at the same time as the greater part of the Fe is estimated to be less than half of the total V-amount.

1 is an example of the influence which the arc temperature produces upon the intensity of the spectral lines, NaCl causing decrease of the arc temperature.*

2 is an evaporation phenomenon, and shows that Fe is not an ideal comparison element in this connection, and should not be used when great amounts of alkalies are present, as V and Fe in this case do not meat the demands of simultaneous evaporation. However, when NaCl is not added, V and Fe vaporize simultaneously from the iron ores, concentrated as well as unconcentrated. And in spite of this, the NaCl-mixtures give a better result (no change in Δ log T) than the iron ores D and E.

As mentioned before, albite and labradorite produce about the same change in Δ log T when added to the iron ore concentrates. But fractionated exposures showed that while in the labradorite mixture V and Fe vaporize simultaneously, the spectra of the albite mixture show the same features as when NaCl is added, but to a less extent. However no difference in the *total* exposures of the labradorite and the albite mixtures with regard to the V- and Fe-lines employed could be detected.

This must mean that it is of no great importance in this case that V and Fe should vaporize at the same time. The inconstancy of the intensity ratio $\frac{\mathrm{V}}{\mathrm{Fe}}$ seems rather to be due to variations in the arc temperature.

The described increase in Δ log T, that is in the intensity ratio $\frac{\mathrm{V}}{\mathrm{Fe}}$, when several compounds are added to the iron ore concentrates,

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* Phenomena like this and others caused by alterations of the physical conditions of the arc are more closely described by W. Rollwagen.(4)

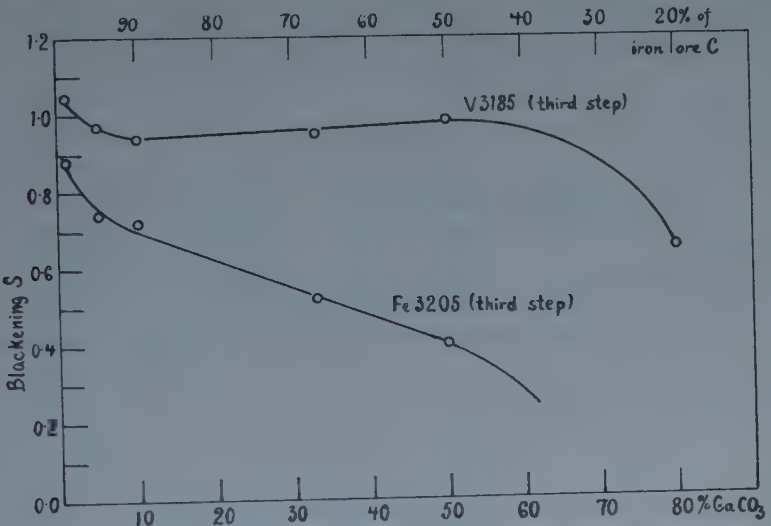

Fig. 6. Influence of $CaCO_3$-content on blackening of V- and Fe-lines.

$$\frac{\%\ V}{\%\ Fe} = \text{const.} = 0.0077.$$

may arise from an increase of the intensity of the V-lines, from a weakening of the Fe-lines, or from a combination of both.

Concerning $CaCO_3$ this question was given a closer examination. Fig. 6 shows the photographic density of the Fe- and V-lines, when the ratio $\frac{\text{percentage of V}}{\text{percentage of Fe}}$ is constant, while the samples contain different amounts of $CaCO_3$. All the samples were photographed on the same plate in order to eliminate any variations due to the developing process.

It is seen that the density of the V-line 3185 is practically constant up to a $CaCO_3$-content of 50 per cent, while it should normally be supposed to decrease, but the density of the Fe-line 3205 decreases as expected. Thus it is proved that when $CaCO_3$ is added, the intensity ratio $\frac{V}{Fe}$ increases according to a rise in the intensity of V.

An examination of other plates showed that this is also valid in the case of D and E and other cases where Δ log T is found to be greater than expected according to the iron ore calibration curve.

The Determination of V in Slags with Fe as a Comparison Element.

It has been mentioned above that the spectrochemical determination of V in slags is subject to the same effect as the determination of V in unconcentrated iron ores, the only difference being that the effect produced in the slags is much greater. But one must also admit, that it is not to be expected that an intensity ratio $\frac{V}{Fe}$ related to the slags, should be applicable to the iron ore calibration curve. Then according to K. Kristoffersen (6) the slags employed can roughly be considered as a mixture of Ca-ferrite ($2\ CaO \cdot Fe_2O_3$) and Ca-silicate ($2\ CaO \cdot SiO_2$) in the proportion about 1 : 4, and in addition to this a RO-phase containing FeO, MnO, and MgO. Thus the slags show a base substance quite different from that of the iron ores, the ores containing rock minerals being included. And in addition to this there is also another important difference, as in the slags V and a great part of Fe occur as silicates.

In order to construct a calibration curve applicable to slags, a series of standard mixtures was prepared by diluting a synthetic slag, S_0, having a V-content equivalent to 2% of the Fe-content, successively with a V-free synthetic slag.

The two synthetic slags were prepared by mixing 58.3% CaO, 25.0% SiO_2 and 16.7% Fe_2O_3 thoroughly in an agate mortar, V being added in preparing one of them. (Vanadium was added as a vanadium oxide compound containing 50.3% V.) These mixtures were pressed to tablets at a pressure of 1000 kg/cm², and then sintered for 18 hours at 1100° C in an electric furnace. The dilution yielded the mixtures S_1, S_2, and S_3 having the following V-contents in percent of the Fe-content: 1.0, 0.333, and 0.1.

Of these mixtures spectra were made in the way described above, and fig. 4 shows the achieved calibration curves (III). The curves are greatly displaced relatively to the iron ore curves, and it is seen that when the iron ore curves are used for the determination of V in slags, the figures come out 6½ times too high when the line pair V 3185—Fe 3205 is used, and 3½ times too high when using the pair V 3056—Fe 3055.

The actual slags with known V- and Fe-content according to chemical analysis, which are previously mentioned, yielded the points enclosed in small triangles. It is seen that the points related to the standard mixtures are lying on a straight line, while those due to the actual slags are not.* But it must be taken into consideration that the absolute V-content of the slags is of the magnitude 0.09—0.15 per cent, and when the chemical analysis in spite of this agree as closely as shown, the check must be considered as good as can be expected.

Some of the slags had been treated with chemical agencies e. g. citric acid, and the residues acccordingly had a Fe_2O_3-content of about 50 per cent, and for these residues new calibration curves must be constructed. As standard mixtures were used the synthetic slags S_0 and S_1 diluted 1 : 1 with Fe_2O_3, and the standard mixtures thus contained 58 per cent Fe_2O_3 and 29 per cent CaO, and the V-content was 0.143 and 0.285 in per cent of the Fe-content.

The resultering calibration curves are as expected displaced to the right relatively to the slag curves, as shown in fig. 4, curve IV.

An Estimation of the $\frac{V}{Fe}$-Method.

From the foregoing it will be seen that the quantitative spectrochemical determination of V in iron ores and slags is subjected to certain difficulties. Quite a lot of calibration curves must be applied as fig. 4 shows, if one is going to examine slags, concentrated iron ores, ores containing rock minerals and so on. Though all these curves must be used, the V-determinations might, when caution and care are applied, give results probably not deviating more than ± 10 relative per cent from the real V-content. The analysis of concentrated iron ores is simple and convenient. As to the ores containing rock minerals the case is more complicated, as the ores nature and approximate amount of rock minerals should first be determined by magnetic separation or in some other way. Concerning the slags each slag type should have its own calibration curve.

But in spite of the convenience in using Fe as a comparison element, it must be admitted that the irregularities and disadvantages connected with this method are so great, that an easier method is desirable.

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* The flat part of the V 3056 curve is due to the fact that the V-line at this concentration nearly disappears in the background (background effect).

It may be added here that the method might be improved by adding e. g. $CaCO_3$ to all the samples in order to obtain more constant conditions, or the samples could be diluted e. g. 10 times with Fe_2O_3. The dilution with Fe_2O_3 has been applied to the iron ores, and is a useful method.

An attempt was then made to find a comparison element which shows the same variations in intensity as V, when different compounds are added to the material to be examined. There was a possibility that Cr might be such an element, and a closer examination showed that Cr is a very suitable comparison element in this connection. The following will show this.

How the Difficulties disappear when Cr is used as a Comparison Element instead of Fe.

A good line was found in the Cr I-line 3034.190 which has no coincidences, and which is of a convenient intensity when Cr is present in amounts of about 10 per cent. The line pair V 3056—Cr 3034 must be considered well suited for the analysis and better than V 3185—Cr 3034, as the distance between the two latter lines is greater than generally desirable. The foregoing has also shown that the line V 3185 is subject to greater variations in intensity than V 3056, and therefore, though V 3185 is by far the stronger line, the chief interest was given to the line pair V 3056—Cr 3034. But the pair V 3185—Cr 3034 was also employed, and the results obtained by using this pair were good also.

The comparison element Cr was added to the samples, and to the standard mixtures in the form of Cr_2O_3, and in the proportion 10 parts of sample to 1 part of Cr_2O_3. To this mixture were added 2 parts of carbon powder as usual, and the working conditions were the same as previously described in this paper, with the exception that the electrodes were intensely preheated for 30 seconds before igniting the arc, in order to prevent spitting, which often occurs when this precaution is not taken.

To get a survey of the applicability of Cr as a comparison element, 1 part of Cr_2O_3 was mixed with 10 parts of each of the following standards (arranged in order of decreasing V-content):

A.........(1.17 % V)
B ....(0.83 % V)
C ....(0.50 % V)
$B + Fe_2O_3$ 1 : 1
E ....(0.23 % V)
D ....(0.17 % V)
S_1 .... (0.117 % V in synthetic slag $\left(\frac{V}{Fe} = 1.0\,\%\right)$)
$S_1 + Fe_2O_3$ 1 : 1
S_2 .... (0.039 % V —»— $\left(\frac{V}{Fe} = 0.333\,\%\right)$)
S_3 .... (0.0117 % V —»— $\left(\frac{V}{Fe} = 0.1\,\%\right)$)

These standards have very different chemical compositions, the base substance varying from iron ore to slag containing about 60 % CaO. But fig. 7 shows that the variations in base substance have only little influence upon the intensity ratio $\frac{V\ 3056}{Cr\ 3045}$. The points belonging to the slags, ores containing rock minerals and mixtures of ores or slags with Fe_2O_3, all fall approximately on the prolongation of the calibration curve constructed for the iron ore concentrates A, B, and C. Thus instead of four or more calibration curves, which must be used when Fe is chosen as a comparison element, the determination of V with Cr as a comparison element can be carried out with the use of one single calibration curve, valid for concentrated and unconcentrated iron ores, and for slags of different compositions. The points in fig. 7 each represent the average of two different determinations. The deviations of the average values from the straight line are with few exceptions less than ± 10 relative per cent, and those deviations are assumed chiefly to be due to some inaccuracy in the weighing or mixing of Cr_2O_3, when this is added to the standards. When the greatest accuracy is demanded, Cr_2O_3 should be added as a mixture of e. g. 20 % Cr_2O_3 in e. g. $CaCO_3$ in the proportion 1 part of this mixture to 1 part of the standards as well as the samples to be analysed, as uncertainties of weighing are in this way considerably reduced.

How little the intensity ratio $\frac{V\ 3056}{Cr\ 3034}$ is affected by changes in the composition of the materials to be examined, is shown in table

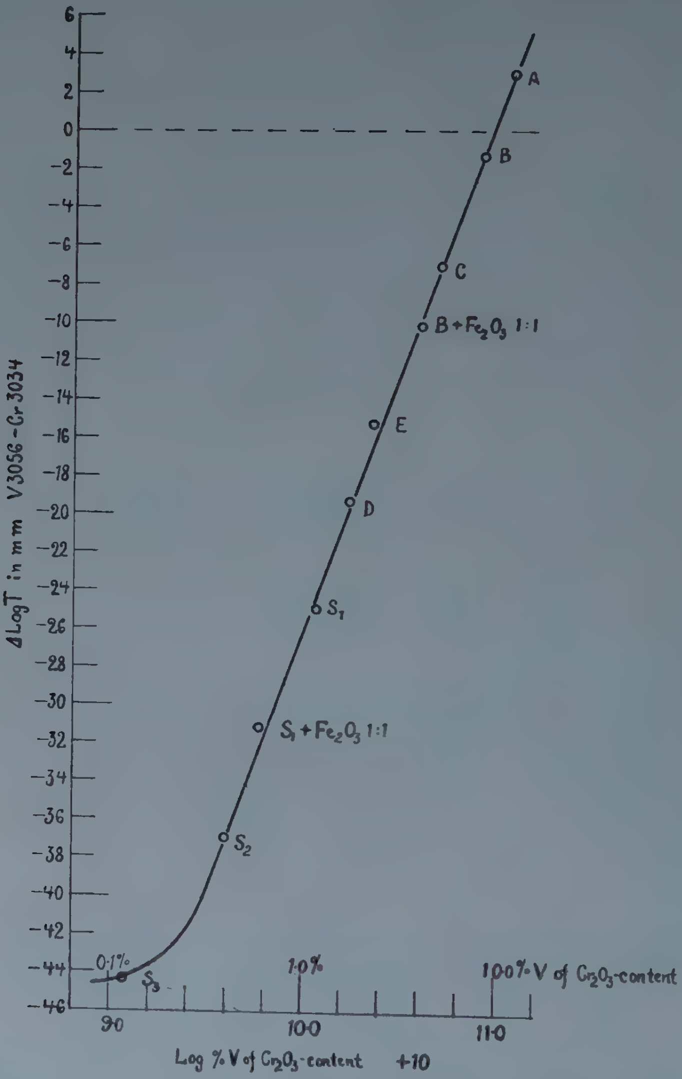

Fig. 7. Calibration curve for the line pair V 3056—Cr 3034, valid for iron ores and slags.

3. It is seen that the addition of $CaCO_3$ has no great influence, and what is interesting too: If Cr_2O_3 is present in an amount of 1 per cent instead of 10, this seems not to affect the result at all. By comparing the mixtures 1, 2, and 3 this is obvious.

Table 3.

	Mixtures examined	log T in mm			Per cent of V in C	
		I	II	Average	Actual V-content	V-content found
1	$(C+Cr_2O_3\ 10:1)+CaCO_3\ 1:9$	—5.5	—7.0	—6.3	0.50	0.54
2	$(C+Cr_2O_3\ 10:1)+CaCO_3\ 1:1$	—6.2	—6.2	—6.2	0.50	0.54
					Per cent of V in the mixtures in brackets	
					Actual V-content	V-content found
3	$(50\%\ C+50\%\ CaCO_3)+Cr_2O_3\ 10:1$ ..	—14.1	—14.1	—14.1	0.25	0.27
4	$(8.5\%\ A+91.5\%\ CaCO_3)+Cr_2O_3\ 10:1$	—28.0	—27.2	—27.6	0.10	0.09
5	$(21.4\%\ A+78.6\%\ CaCO_3)+Cr_2O_3 10:1$	—13.5	—13.9	—13.7	0.25	0.28

The fact that the presence of only one per cent of Cr_2O_8 in the material to be analysed is sufficient for a V-determination is very advantageous and can be utilized by the analysis of slags. Then the actual slags previously mentioned contain about one per cent of Cr_2O_8. If this Cr_2O_8-content is known, the V-determination is carried out without adding Cr_2O_8, and when the Cr_2O_8-content is unknown, both V and Cr_2O_8 are determined in one operation as follows: Spectra are taken of the slag with no extra Cr_2O_8 added, and of the same slag mixed 10:1 with Cr_2O_8. From the calibration curve are found the concentration ratios $\frac{V}{Cr_2O_8}$ (a and b) for both samples, and the contents of V and Cr_2O_8 in the original slag are found from the equations:

I
$$\frac{\%\ Cr_2O_{8\ \text{orig.}}}{\%\ V_{\text{orig.}}} \cdot 100 = a$$

II
$$\frac{\%\ V_{\text{mix.}}}{\%\ Cr_2O_{8\ \text{mix.}}} \cdot 100 = \frac{\%\ V_{\text{orig.}} \cdot \frac{10}{11}}{\%\ Cr_2O_{3\ \text{orig.}} \frac{10}{11} + 10 \cdot \frac{10}{11}} \cdot 100 =$$

$$\frac{\%\ V_{\text{orig.}}}{\%\ Cr_2O_{8\ \text{orig.}} + 10} \cdot 100 = b$$

i. e.

$$\% \mathrm{V} = \frac{a \cdot b}{10\,(a-b)}$$

and

$$\% \mathrm{Cr_2O_3} = \frac{10 \cdot b}{a-b} \qquad \text{in the original slag.}$$

a is the concentration ratio $\frac{V}{Cr}$ for the original slag and *b* is the concentration ratio $\frac{V}{Cr}$ for the 10 : 1 slag—Cr_2O_3 mixture, both ratios in per cent.

In table 4 is as an example shown the determination of V and Cr_2O_3 in the slag 55 b, and the results are compared with the chemical data (6).

Table 4.

Material analysed	Δ log T V-Cr in mm			$\frac{Cr}{V}$ in %	% V		% Cr_2O_3	
	I	II	Average		Spectr.	Chem.	Spectr.	Chem.
Slag 55 b	— 0.6	— 0.9	— 0.8	8.7 (a)	0.08	0.07	0 93	1.07
Slag 55 b + Cr_2O_3 10 : 1	—29.5	—29.2	—29.4	0.74 (b)				

Summary.

Two spectrochemical methods for determining vanadium in iron ores and in slags are described. By the first method the intensity of the V-lines 3185 and 3056 is compared with the intensity of the Fe-lines 3205 and 3055 produced by the Fe-content which the sample contained itself. Concentration-calibration curves were constructed by plotting the log exposure time ratios (Δ log T ≈ log intensity ratio) $\frac{V\ 3185}{Fe\ 3205}$ and $\frac{V\ 3056}{Fe\ 3055}$ in mm against log concentration ratio $\frac{V}{Fe}$. As standards were used chemically analysed iron ores and slags, and synthetic slags.

It is shown that the intensities of the V-lines applied are strongly affected by changes in the base substance, as $CaCO_3$, Al_2O_3, albite, labradorite, and olivine cause an increase of the V-line intensity. The rise in Δ log T produced by each of these compounds are quantitatively determined, and it is shown that the total increase in

Δ log T produced by an albite—labradorite—olivine mixture can be calculated by adding up the partial rises produced by each of the component minerals. It is shown how the V-determinations, in spite of the variations in intensity due to changes in base substance, are carried out by using one separate calibration curve for each base substance.

By the second method 1 part of Cr_2O_3 is added for comparison to 10 parts of the standards and samples. The relative exposure time ratio $\frac{V\ 3056}{Cr\ 3034}$ is plotted against log concentration ratio $\frac{V}{Cr_2O_3}$, and thus one single calibration curve is constructed, which is valid for iron ores and slags. It is shown that $\Delta \log T_{V-Cr}$ is very little affected by changes in base substance.

A method for determining V and Cr in slags spectrochemically by two spectra is described.

Acknowledgement.

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A CONTRIBUTION TO THE DETERMINATION OF MANGANESE IN SILICATES

BY

LARS LUND

WITH 1 FIGURE IN THE TEXT

The usual method of determining manganese in silicates is a colorimetric comparison of $KMnO_4$ with a standard solution after oxidizing with KJO_4 (1). This method works fairly well when the amount of manganese to be determined does not exceed 0.5% of the silicate. For larger quantities it is not adequate since the determination of aluminium by difference depends upon an accurate determination of manganese and iron.

During an investigation by mag. scient. H. Neumann on Kongsberg minerals I had the pleasure of doing some mineral analyses, partly independant and partly together with him. Amongst others I had the opportunity of analysing a specimen of axinite, which, containing nearly 4.5% MnO, at once confronted me with the above problem. In this case the first difficulty was to decide in which stage of the analyses the precipitation of manganese should be effected. (It was at once evident that this amount could not be determined colorimetrically in the usual way.) The common method of precipitating manganese together with the sesquioxides after oxidizing with bromine-water is not recommendable in this case since contamination with calcium and magnesium is apt to occur (2).

Different procedures were tried: For instance a colorimetric determination of the manganese that was precipitated with the sesquioxides without oxidation with bromine water, and a subsequent determination of the chief amount of manganese (precipitated as sulfide from an acetic acid solution) (3). Or precipitation of manganese with "oxin" (4). But none of these methods were satisfactory.

Then I came across a paper by H. Lang and F. Kurtz on the determination of manganese (5). And the method suggested by these authors proved to be highly suitable for silicate analysis.

I shall give a brief account of the principles involved: Mn^{2+} is oxidized to Mn^{7+} with $K_2S_2O_8$ and $AgNO_8$ as a catalyzer. Some HPO_8 is added to make the oxidizing process irreversible. Mn^{7+}

is now titrated with Fe^{2+} using diphenylamine as indicator. This indicator gives a very distinct and sudden change of colour turning from dark blue-violett to light green. At the end point the change takes place with half a drop n/50 Fe^{2+} (0.02 ml).

To test the method the following solutions were prepared:

I. 3.9508 g $KMnO_4$ solved in water reduced with SO_2 filled up to 500 ml
II. 0.6585 » » » » » » » » » » » 250 »
III. 1.5803 » » » » » » » » » » » 500 »
IV. Contains ca. 0.1 mg MnO per ml.

The $FeSO_4$-solutions are prepared in large store-bottles (10 l). One n/10 and another n/50 and are kept under CO_2-pressure.

A good arrangement is shown in fig. 1. Solutions kept in this way preserve nearly constant titer for years.

The $FeSO_4$-solutions are adjusted against $K_2Cr_2O_7$. It is necessary to add ca. 5 ml H_3PO_4 (sp. w. 1.7) to each sample, to make the change of colour more distinct.

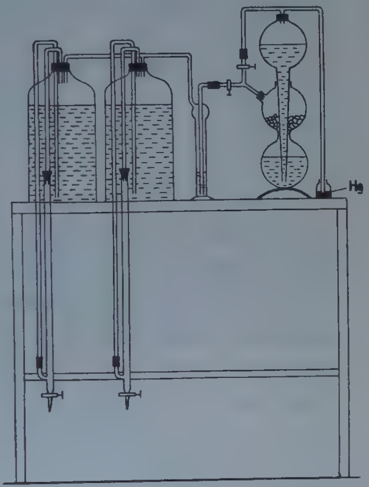

Fig. 1. Arrangement for titration of manganese

Procedure: To the solution which must not contain Cl^--ions ca. 10 grams of HPO_3 is added and it is warmed until this is dissolved. Then 10 ml n/10 $AgNO_3$ and ca. 2 grams of $K_2S_2O_8$ dissolved in a small amount of water are poured in. It is good to add two or three small peces of glass-capillars to prevent bumping. The solution is kept at a boil for 20 minutes to destroy excess of $K_2S_2O_8$, cooled under the tap, titrated to pink. Now 2 or 3 drops of as olution of diphenylamin in phosphoric acid is added and the titration is continued till the solution turns green.

The results of test-analyses are tabulated below:

Mn-solution I:	n/10 $FeSO_4$	Calculated	Error %
	24.57 ml	24.53 ml	0.2
	24.58 -		0.2
	24.58 -		0.2
	49.36 -	49.35 -	0.0
	49.35 -		0.0 added 3 g CaO
	49.37 -		0.0 - 3 g MgO

	n/10 $FeSO_4$	Calculated	Error %
Mn-solution II:	16.47 ml	16.46 ml	0.1
	16.47 -		0.1
	16.41 -		−0.3
	16.47 -		0.1
	16.57 -		0.7
	16.50 -		0.2
	20.53 -	20.61 -	−0.4
Mn-solution III:	19.78 -	19.74 -	0.2
	19.73 -		−0.1
Mn-solution IV:	n/50 $FeSO_4$		
	8.80 ml added ca. 20 mg TiO_2		
	8.79		
	24.74		
	24.72		
	24.72 - added ca. 20 mg TiO_2		

The determination of Manganese in silicates can be done in two ways. Either precipitate manganese together with the sesquioxides after oxidizing with bromine-water, or let manganese distribute itself among this and the following precipitates. Then some of it will be co-precipitated with the sesquioxides, some together with calcium, and the chief amount will appear as phosphate together with magnesium. However, manganese is not quantitatively precipitated in this way (6), and the filtrate must be evaporated to dryness, Cl^--ions driven off by repeated evaporations with nitric and sulfuric acids and manganese determined in the residue.

In a common rock-analysis where the amount of manganese does not exceed 0.5 % the first method is sufficiently accurate. Then the sesquioxides are fused with $K_2S_2O_7$ in the ordinary way and an aliquot part is taken out ($^1/_5$ is sufficient) for the determination of manganese.

If greater amounts of manganese is present as the case was with the axinite, it is better to let manganese disperse. Manganese in the sesquioxides is determined as just described. The precipitates of CaO and $Mg_2P_2O_7$, after having been weighed, are dissolved in H_2SO_4 and manganese oxidized and titrated as mentioned above.

The chief objection to this method is that both calcium and magnesium are determined indirectly. But in this case it will not involve any great error since manganese is weighed as the well defined Mn_3O_4 and $Mn_2P_2O_7$ respectively, and the subsequent determination of manganese can be conducted with great accuracy.

In the table below I give the distribution of manganese in the different precipitates during the analyses of the axinite.

	I	II
In sesquioxides	0.63 %	0.53 %
» Ca-precipitate	0.67 -	0.44 -
» Mg-precipitate	3.00 -	3.22 -
» filtrate	0.12 -	0.24 -
Sum	4.42 %	4.43 %

For more than a year this method of determining manganese in rocks has been used with great advantage in the laboratory of the Mineralogical Institute. In regard to both time and accuracy it is preferable to the colorimetric methods now generally applied by silicate chemists.

Acknowledgements. I want to express my gratitude to Professor dr. Tom. F. W. Barth, the Director of The Mineralogical Institute for placing all the facilities of his laboratories at my disposal.

I also want to thank mag. scient. H. Neumann for valuable discussions.

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OM REGELMESSIG SAMMENVOKSING AV KRYSTALLINDIVIDER

AV

IVAR OFTEDAL

Forelesning holdt den 9. juni 1941.

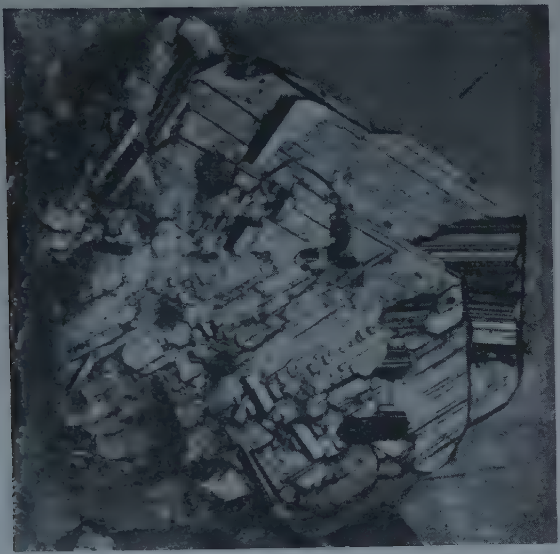
MED 11 FIGURER I TEKSTEN

I naturen opptrer krystallene i aggregater av forskjellig slag, slik at hvert individ er i mer eller mindre direkte berøring med sine naboindivider. En krystall kan sitte direkte på en annen krystalls velutviklete flater, den kan være mer eller mindre nedsenket i eller helt gjennomvokse den annen krystall, eller hele aggregatet kan bestå av individer som ligger an mot hverandre etter uregelmessige grenseflater. Av slike iakttakelser slutter vi at det ene individ var ferdigdannet da det annet begynte å krystallisere, at det eldre individ fortsatte å vokse en tid etter at det yngre var begynt å dannes, eller at veksten av begge individer som helhet foregikk samtidig. I alle tilfelle har veksten av det ene individ foregått under innflytelse av det annet. I alminnelighet innskrenker denne innflytelse seg til en hindring i den frie vekst, slik at individet delvis eller helt kommer til å mangle sin karakteristiske krystallbegrensing. Men i en rekke tilfelle kan innflytelsen dessuten være av den art at de to individer kommer til å innta bestemte krystallografisk definerbare stillinger i forhold til hverandre. Det ene individ har da virket orienterende på det annet under dettes vekst. Med vårt kjennskap til krystallenes struktur må vi forestille oss bestemte prinsipielle betingelser for at en slik orienterende virkning skal komme i stand. Det er tydeligvis de atomære krefter som utgår fra en krystalls overflateskikt som her er virksomme. Disse krefters fordeling er en funksjon av partikkelanordningen i de strukturplan som er parallelle med overflateskiktet, og vi må derfor vente at det påvoksende partikkelskikt mer eller mindre nøyaktig vil komme til å avspeile denne anordning. Vi får da på begge sider av grenseflaten innbyrdes parallelle strukturplan som viser visse analogier i sin partikkelanordning; spesielt må vi vente at det i de to slags strukturplan finnes gittervektorer som stemmer nær overens.

En slik analogi mellom ett strukturplan i bærerkrystallen og ett strukturplan i den påvoksende substans, altså en todimensjonal strukturanalogi, må vi anta er en *nødvendig* betingelse for en orientert påvoksing. Hvor vidtgående denne analogi må være kan bare et nøyere studium av det foreliggende materiale vise; det samme gjelder spørsmålet om betingelsen er tilstrekkelig. Det er klart at sammenvoksingsflaten ved ren todimensjonal strukturanalogi for hver av de to krystaller må bli parallell med det strukturplan som har analog bygning i dem begge. Denne art orientert sammenvoksing vil altså ikke forutsette noe bestemt om andre strukturelementers — f. eks. de krystallografiske aksers — gjensidige stilling.

Hvis de to krystaller viser strukturanalogier også i den tredje dimensjon skulde betingelsen for regelmessig sammenvoksing være til stede i forsterket grad. Det mest fullkomne tilfelle av dette har vi når de to krystaller har samme struktur og nær samme dimensjoner. Da vil alle strukturplan i den ene krystall — og dermed også de krystallografiske akser — bli orientert parallelt med de tilsvarende i den annen. I slike parallellsammenvoksinger kan grensen mellom individene ha en hvilken som helst regelmessig eller uregelmessig form, da ethvert strukturplan har betingelse for å opptre som sammenvoksingsflate. Også for regelmessige sammenvoksinger på grunn av tredimensjonal strukturanalogi gjelder at de tillatelige avvikelser fra den fullkomne analogi må finnes ved studium av det foreliggende materiale. Som det ideale spesialtilfelle av parallellsammenvoksing kan vi anse alminnelig krystallvekst. Her er bærerkrystallen og den påvoksende substans identiske både krystallografisk og kjemisk. På grunn av denne analogi mellom krystallvekst og regelmessig sammenvoksing av ulikeartete krystaller ligger det nær å slutte at også en annen betingelse — ved siden av den nevnte geometriske — må være oppfylt for at en slik sammenvoksing skal være mulig. Tenker vi oss en ionekrystall som er i vekst så må vi forestille oss vekstprosessen slik at det på hver krystallflate anlegges nye nettplan identiske og parallelle med de allerede eksisterende og slik at strukturen fortsettes ubrutt. Hver partikkel i det nyanlagte nettplan har da sitt motstykke i det nærmest underliggende identiske nettplan; spesielt svarer elektropositive partikler til elektropositive og elektronegative partikler til elektronegative. Det synes rimelig å anta at noe liknende må gjelde også når de nyanlagte nettplan består av en annen substans enn bærerkrystallens, at det altså er en betingelse for regelmessig sammenvoksing mellom ulikeartete substanser at de partikler som kommer til å svare til hverandre i sammenvoksingsflaten er av samme polaritet. Som en mellomting mellom alminnelig krystallvekst og parallellsammenvoksing mellom forskjellige substanser kan vi anse veksten av isomorfe blandingskrystaller mellom to komponenter, eventuelt under forandring av mengdeforholdet mellom komponentene. I det siste tilfelle får vi sonarbyggete krystaller. Dannelsen av isomorfe blandingskrystaller fordrer en meget vidtgående analogi i struktur, dimensjoner og kjemisk natur mellom de to komponenter. Under en krystalls vekst kan det forekomme at de nye nettplan som anlegges på en flate og parallelt med denne fra et visst punkt av inntar en annen stilling enn den normale til de underliggende. Der må da være to forskjellige muligheter for krystallens vekst, og denne annen mulighet fører til en tvillingkrystall med den nevnte flate som tvillingplan og sammenvoksingsplan. I denne flate er det strukturanalogi mellom de to individer, og tvillingsammenvoksingen grunner seg derfor iallfall minst på en strukturanalogi i to dimensjoner, men ofte kommer andre strukturanalogier i tillegg. Jeg skal ikke her gå nærmere inn på tvillingkrystaller. Men etter det som før er sagt ligger det nær å anta at tvillingsammenvoksinger som har tvillingplanet til tvillinggrense grunner seg vesentlig på todimensjonal strukturanalogi, mens de tvillinger som viser en uregelmessig tvillinggrense grunner seg på mer eller mindre fullkommen tredimensjonal strukturanalogi, naturligvis bortsett fra den struktur-identitet som er til stede når individene står i parallellstilling.

Det har vært antatt at vi også kan ha regelmessige sammenvoksinger på grunnlag av éndimensjonal strukturanalogi, altså slik at bare en punktrekke i hver struktur skulde vise analogi. I sammenvoksingen skulde det da bare være en soneakse som var felles for begge individer, og begge skulde være fritt dreibare om denne. Fersmanns resultater angående skriftsammenvoksingen mellom kvarts og feldspat(1) er blitt tolket på denne måten(2). Imidlertid er det meget vanskelig å forestille seg hvordan en slik éndimensjonal strukturanalogi alene skulde være tilstrekkelig til å orientere to krystallindivider i forhold til hverandre, og det hele må ansees som meget tvilsomt. W. H. Taylor, som har bestemt feldspatstrukturen, uttaler seg meget forsiktig om skriftsammenvoksingen med kvarts og sier at den antakelig må henge sammen med visse trekk som er felles for de to strukturer(3).



B. Mauritz fot.

Fig. 1. Etter et stykke fra St. Gotthard i Min.- geol. museums samling. Basisflate av jernglans med orienterte prismer av rutil. (× 4 ½)

Etter disse mer teoretiske betraktninger skal jeg nå omtale noen viktige iakttakelser som er gjort over regelmessige sammenvoksinger og vise at de bekrefter teorien og på visse punkter fører til en nærmere utforming av den.

Jeg skal først i all korthet nevne de viktigste undersøkelser som hittil er utført over regelmessige sammenvoksinger mellom forskjelligartete krystaller. I mineralriket har fenomenet vært kjent i lang tid. Jeg skal nevne to klassiske eksempler, staurolitt—distén og jernglans—rutil. Lovene for den gjensidige orientering er her: (010)s // (100)d, [001] s // [001] d og (111) j // (100) r, $[2\bar{1}\bar{1}]$ j // [001] r; i det siste tilfelle er det derfor 3 likeverdige orienteringer (Fig. 1). I 1878 gjennomgikk Sadebeck(4) ca. 20 eksempler som da var kjent. Han mente å kunne fastslå at de to individers krystallografiske akser var av vesentlig betydning for orienteringen, slik at en eller flere av disse måtte bli parallellorientert. I 1902 bygget Wallerant(5) videre på Sadebecks undersøkelser ved hjelp av ca. 50 forskjellige regelmessige sammenvoksinger. Han framhevet analogien mellom krystallvekst, dannelsen av isomorfe blandingskrystaller, og orientert påvoksing.

Han kom til at minst 2 viktige krystallografiske retninger i hvert individ måtte orienteres parallelt. Mügge(6) behandlet i 1903 alt materiale som da var tilgjengelig — over 70 eksempler på regelmessig sammenvoksing. Mügge fant at koinsidensen av akser og symmetrielementer var av mindre betydning. For ham var det vesentlige at det fantes flater som viste like eller tilnærmet like kantvinkler i de to krystaller, og orienteringen grunnet seg da på at en slik flate hos hver krystall ble innbyrdes likedan orientert; at de to krystallers akser og symmetrielementer derved kunde få ganske forskjellige retninger anså han som uvesentlig. Han sammenlikner også den virkning som den ene krystall utøver på den annen under dennes vekst med katalyse, og han tilføyer at det nesten alltid er identiske atomer eller atomgrupper til stede i de to individer som vokser sammen orientert. De nevnte arbeider grunner seg nesten utelukkende på studiet av naturlige regelmessige sammenvoksinger. Men der er også gjort eksperimentelle arbeider over veksten av kunstige krystaller på hverandre og på mineraler. Mer tilfeldig ble slike forsøk gjort av Wakkernagel (1825)(7) og Frankenheim (1836)(8). Frankenheim oppdaget for øvrig den orienterte påvoksing av natronsalpeter på kalkspat og av KCl, KBr og KJ på glimmer. Den første systematiske undersøkelse over disse kunstige påvoksinger ble gjort av Barker i 1908(9). Det var et omfattende arbeid som ga viktige resultater. Han gikk ut fra at studiet av en krystalls vekst på en annen krystall måtte gi visse opplysninger om forholdet mellom de to krystallers strukturer, og han fant også resultater som ble bekreftet da den direkte undersøkelse av krystallenes struktur noen år senere ble muliggjort. Han viste at Mügges betingelse om de overensstemmende kantvinkler ikke var tilstrekkelig til å muliggjøre en orientert påvoksing. Det er ikke bare *formen* av visse nettmasker i de to strukturer som må vise likhet, men også deres relative *dimensjoner* har avgjørende betydning. Barker undersøkte bl. a. påvoksingen av de kubiske alkalihalogenider og beslektete stoffer på hverandre; det dreide seg her om parallellorientering av individene. Han fant at parallellorienteringen av to stoffer var avhengig av en nær overensstemmelse mellom deres molekylarvolum og mellom deres dermed sammenhengende topiske parametre. Men de topiske parametre for to isostrukturelle stoffer står i samme innbyrdes forhold som deres absolutte gitterdimensjoner, og det følger herav at en parallellsammenvoksing mellom to isostrukturelle krystaller bare er mulig når deres gitterdimensjoner stemmer nær overens. Da parallellsammenvoksingen uteble i visse tilfelle da den var ventet på grunn av likhet i de topiske parametre, sluttet Barker at det her ikke kunde dreie seg om isostrukturelle stoffer, at det altså blant de kubiske alkalihalogenider fantes to forskjellige strukturtyper. Disse to typer har senere vist seg å svare til NaCl-typen og CsCl-typen. Friedel (1911)(10) førte Barkers ideer videre på grunnlag av sine studier over tvillingkrystaller. Han fant at regelmessig sammenvoksing også var mulig når en m-dobbelt gitterselle i det ene individ svarte til en n-dobbett gitterselle i det annet (m og n hele tall.). Han antar videre at det er tilstrekkelig at et slikt forhold består mellom visse *nettmasker* i de to individer, altså at en m-dobbelt nettmaske i det ene individ i form og størrelse stemmer nær overens med en n-dobbelt nettmaske i det annet; sammenvoksingen kan da bare finne sted etter den strukturflate i hvert individ som inneholder denne nettmaske. De to substansers krystallsymmetri og kjemiske natur er uten betydning for sammenvoksingen. Alle de nevnte arbeider ble utført før det var mulig å undersøke krystallenes struktur med røntgenstråler. Etter at praktisk talt alle enkle krystallstrukturer og en del mer kompliserte var blitt bestemt og kunde benyttes har Royer(11) i 1928 publisert et meget betydningsfullt arbeid på området. Likesom Barker støtter han seg til eksperimentelle undersøkelser over kunstige krystallers vekst på andre. Først etterpå prøver han sine resultater på en rekke eksempler fra mineralriket. Han benytter denne framgangsmåte vesentlig fordi man i laboratoriet kan velge sine forsøksbetingelser, velge krystaller med enkle og godt fastslåtte strukturer, og gjenta forsøkene så mange ganger man vil og dermed skille lovmessige orienteringer fra tilfeldige. Han utfører og kontrollerer sine forsøk med største omhu for å sikre seg at han virkelig får dannet de krystallarter som er tilsiktet. Dette gjelder især når bærerkrystallen er oppløselig i den veske som den påvoksende krystall krystalliserer av. Helt bortsett fra det tilfelle at de to substanser reagerer kjemisk med hverandre kan vi da lett få dannet blandingskrystaller mellom dem. For å konstatere om han har fått blandingskrystaller eller krystaller av de rene substanser bruker Royer vesentlig lysbrytningsbestemmelser etter immersjonsmetoden, utarbeidet til å gi en tilstrekkelig høy grad av nøyaktighet. På denne måten fant han bl. a. at enkelte av Barkers resultater var feilaktige, da de viste seg å bero på utilsiktet dannelse av blandingskrystaller. Videre fant Royer, spesielt under sine forsøk over orientert påvoksing på glimmer, at

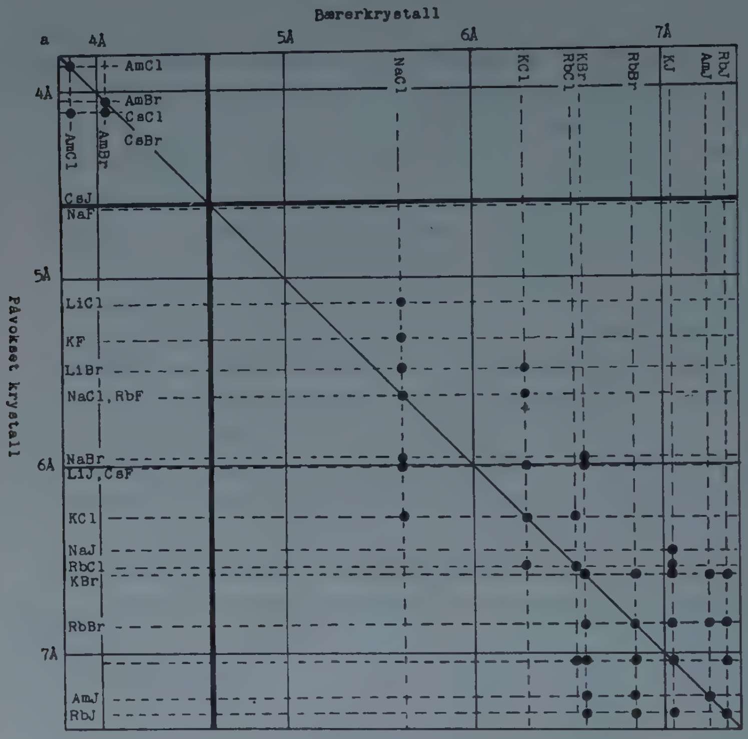


Fig. 2.

bærerkrystallens overflate måtte være absolutt ren, helst en spalteflate framstilt umiddelbart før forsøket. Han sluttet herav, i forbindelse med visse andre iakttakelser, at bare det aller ytterste nettplan hos bærerkrystallen kunde spille noen vesentlig rolle for orienteringen av den påvoksende krystall.

Royers resultater angående parallellsammenvoksing mellom de kubiske alkalihalogenider innbyrdes er framstilt på fig. 2. Jeg har framstilt dem mer gjennomført grafisk enn Royer selv har gjort. Dessuten har jeg sløyfet en del tilfelle av parallellsammenvoksing som ikke var sikkert konstaterbare på grunn av dannelsen av blandingskrystaller. For øvrig er denne Royers tabell i det vesentlige en korrigert og forbedret utgave av en liknende som allerede Barker hadde oppstilt. Både langs bærerkrystallenes og de påvoksete krystallers akse er avsatt en skala i Ångström-enheter og på begge akser er hver krystallart markert ved en streket perpendikulær på det sted som svarer til dens gitterkonstant. Krysspunktene mellom de to sett strekete linjer svarer til de påvoksingsforsøk som Royer har utført, men bare der hvor krysspunktene er markert konstaterte han med sikkerhet parallellorientering mellom de to krystallarter. Krysspunkter som faller på den inntegnete diagonal svarer til påvoksing av bærerkrystallens egen substans. De tykke linjer deler diagrammet opp i felter for CsCl- og NaCl-strukturer. Vi ser at orientert påvoksing av en krystall bare finner sted når dens gitterkonstant ikke avviker for meget fra bærerkrystallens. Toleransen for avvikelsen dreier seg om 10 % og synes maksimalt å gå opp til 12 % av gitterkonstantene. Påvoksingen foregår her på alle bærerkrystallens flater, også på uregelmessige overflater, slik som det er å vente på grunn av den fullstendige tredimensjonale strukturanalogi som her er til stede, og alle tilsvarende retninger i de to krystaller blir som nevnt parallelle innbyrdes. Vi ser at f. eks. krystaller av KCl og NaCl danner parallellsammenvoksinger med hverandre. På den annen side er det vel kjent at disse to salter ikke danner isomorfe blandingskrystaller med hverandre i merkbar utstrekning. Den betydelige forskjell i gitterkonstantene, som skriver seg fra anionenes meget forskjellige størrelse, forhindrer altså dannelsen av blandingskrystaller men ikke den orienterte sammenvoksing. Vi ser også at to krystaller som danner orienterte sammenvoksinger ikke behøver å ha noe ion felles, f. eks. LiJ, CsF, RbF, LiBr og KF på NaCl. — Av andre ting fra Royers meget rikholdige arbeid skal jeg nevne hans forsøk over påvoksing av alkalihalogenider på sulfider og oksyder med NaCl-struktur, og spesielt forsøkene med blyglans som bærerkrystall. Han fikk her parallellorientering av en hel rekke salter som alle hadde NaCl-struktur med gitterkonstanter mellom 5.56 Å og 6.55 Å, mens de salter som hadde gitterkonstanter utenom dette område krystalliserte uorientert på blyglansen. Blyglansens egen gitterkonstant er 5.94 Å, og toleransen for forskjellen i gitterkonstantene er derfor 6 % og 10 %. Her er bærerkrystallen av en vesentlig annen kjemisk natur enn de påvoksete krystaller; like ens har partiklene andre valenser. Interessant er påvoksingen av natriumbromid på en blyglans-spalteflate. Natriumbromid krystalliserer ved alminnelig temperatur av vandig oppløsning som det monokline $NaBr \cdot 2H_2O$. Men hvis vi lar den mettete oppløsning krystallisere på en blyglans-spalteflate så får vi delvis dannet krystaller av det kubiske NaBr, som da er orientert på blyglansen. De orienterende krefter fra blyglansoverflaten er således

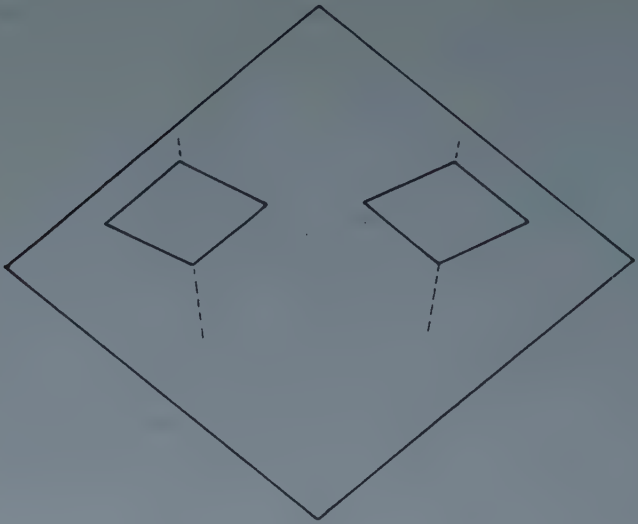


Fig. 3.

i stand til å opprettholde det vannfri kubiske salt utenfor dets normale stabilitetsområde, åpenbart fordi dets gitterkonstant (5.96 Å) stemmer meget nøyaktig med blyglansens. Av andre sammenvoksinger i parallellstilling som er undersøkt av Royer kan nevnes den lenge kjente mellom kalkspat og natronsalpeter, som for øvrig ennå senere, i 1930, er blitt nøye bearbeidet av Maria Settele(12). Til tross for at vi her har en meget vidtgående tredimensjonal strukturanalogi er sammenvoksingen bare i visse tilfelle strengt parallell, nemlig når påvoksingen finner sted på basis eller på prismeflatene $2\bar{1}\bar{1}$ som har samme innbyrdes stilling i begge krystallarter. Hvis påvoksingen finner sted på en romboederflate foregår dette slik at en tilsvarende romboederflate på salpeterkrystallen blir strengt parallell med denne. Men da romboedervinkelen hos kalkspat og natronsalpeter er litt forskjellige kan det ikke bli noen streng innbyrdes parallellitet for de andre to romboederflater. De krystallografiske akser i de to krystaller kommer derfor til å få en litt forskjellig retning. Den videre orientering av de to parallelle romboederflater er, som allerede angitt av Barker, slik at en romboederkant i den ene blir parallell med en romboederkant i den annen. På denne måte oppstår det på hver romboederflate to muligheter for orienteringen (Se fig. 3. Her er forskjellen i vinklene sterkt overdrevet.), men forskjellen mellom disse orienteringer (47′) er så liten at den lett blir oversett. Undersøker vi påvoksingen

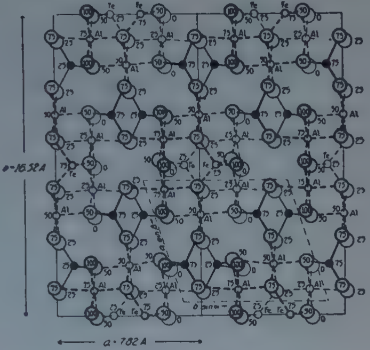


Fig. 4.

av natronsalpeter på de andre trigonale karbonater (dolomitt, magnesitt, jernspat osv.), så viser det seg at parallellorienteringen her iallfall er meget vanskeligere å få til enn på kalkspat. Ved sammenlikning av gitterdimensjoner og romboedervinkler hos de forskjellige karbonater og hos natronsalpeter kan vi herav slutte at overensstemmelse i gitterdimensjonene er viktigere for den orienterte påvoksing enn overensstemmelse i vinklene. Den regelmessige sammenvoksing $CaCO_3$-$NaNO_3$ viser atter at ionene i de to krystaller kan ha forskjellig ladning.

Av andre regelmessige sammenvoksinger på grunn av strukturanalogi i tre dimensjoner skal vi nevne det klassiske eksempel staurolitt—distén. Krystallstrukturene for begge disse mineraler ble bestemt av Náray-Szabó og medarbeidere (13) i 1929, og det viste seg at de to strukturer var meget nær beslektet. Fig. 4 viser en projeksjon av staurolitt-strukturen på (001)-planet. Det område som er omgitt av de strekete linjer svarer nøyaktig til en elementærselle av distén-strukturen, og det kan i figuren, som svarer til 2 staurolittseller, tas ut tilsammen 4 slike områder ordnet i 2 rader. Fjerner vi disse disténseller, som tilsammen representerer 16 Al_2SiO_5 så blir det tilbake 2 smale rader med sammensetningen 8 $Fe(OH)_2$. Hvis vi altså under veksten av en staurolittkrystall fra et visst punkt av lar være å sjalte inn de tynne jernhydroksydskikt, så blir det deretter en disténkrystall som vokser videre på staurolitten, og den har nøyaktig den orientering til staurolittkrystallen som vi finner i de naturlige sammenvoksinger. Dette er en spesiell art tredimensjonal strukturanalogi; de to krystaller er i virkeligheten identiske, bortsett fra de skillevegger av $Fe(OH)_2$ som opptrer i staurolitten, og som merkelig nok er i stand til å heve symmetrien fra triklin til rombisk. På grunn av de spesielle forhold her skulde vi vente at sammenvoksingsflaten oftest vil være (010) hos staurolitt og (100) hos distén, og dette er også faktisk tilfelle.

Som grunnet på tredimensjonal strukturanalogi må vi også regne parallellsammenvoksingen mellom tysonitt CeF_3 og bastnäsitt $CeFCO_3$

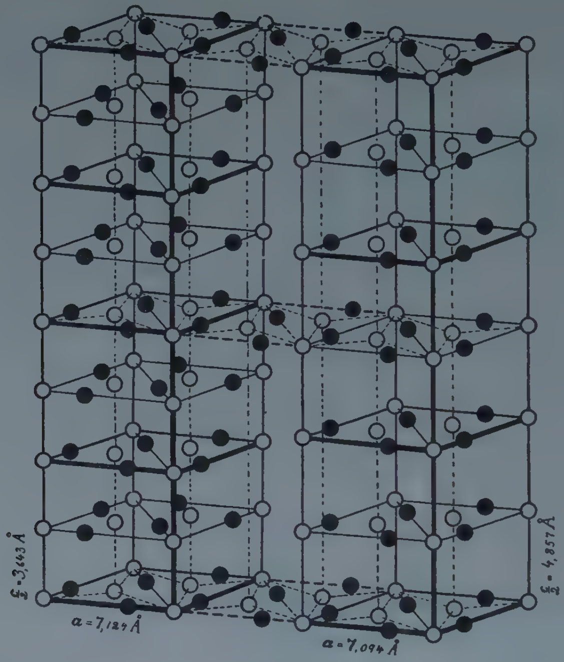


Fig. 5.

(Ce = Ce, La . . .) (14). I Fig. 5 er en del F-ioner hos tysonitt (til venstre) og CO_3-ionene hos bastnäsitt sløyfet. Vi ser at basisflatene er praktisk talt identisk bygget og således skulde danne et utmerket grunnlag for sammenvoksing etter disse flater ved todimensjonal strukturanalogi. Men dessuten ser vi at de loddrette avstander mellom identiske basis-strukturplan i de to krystaller er nøyaktig kommensurable, og slik at 2 identitetsperioder hos tysonitten svarer til 3 identitetsperioder hos bastnäsitten. Hvis altså ett basis-strukturplan er felles for et tysonitt- og et bastnäsitt-individ, så vil det samme gjelde for et bestemt utvalg av de øvrige basis-strukturplan. Strukturanalogien i den tredje dimensjon blir altså her av en mindre fullkommen art og svarer til Friedels analogi mellom multiple seller i de to strukturer. Men analogien er iallfall her tilstrekkelig til at sammenvoksingen kan finne sted etter vilkårlige krystallflater, slik at grensen mellom individene kan få en uregelmessig form. Vi har her et typisk eksempel på at en serie nettplan er felles for begge strukturer og fortsetter praktisk talt uforandret over grensen mellom individene. Slike såkalte simultane nettplan, som er like ikke bare i partikkelanordning og dimen-

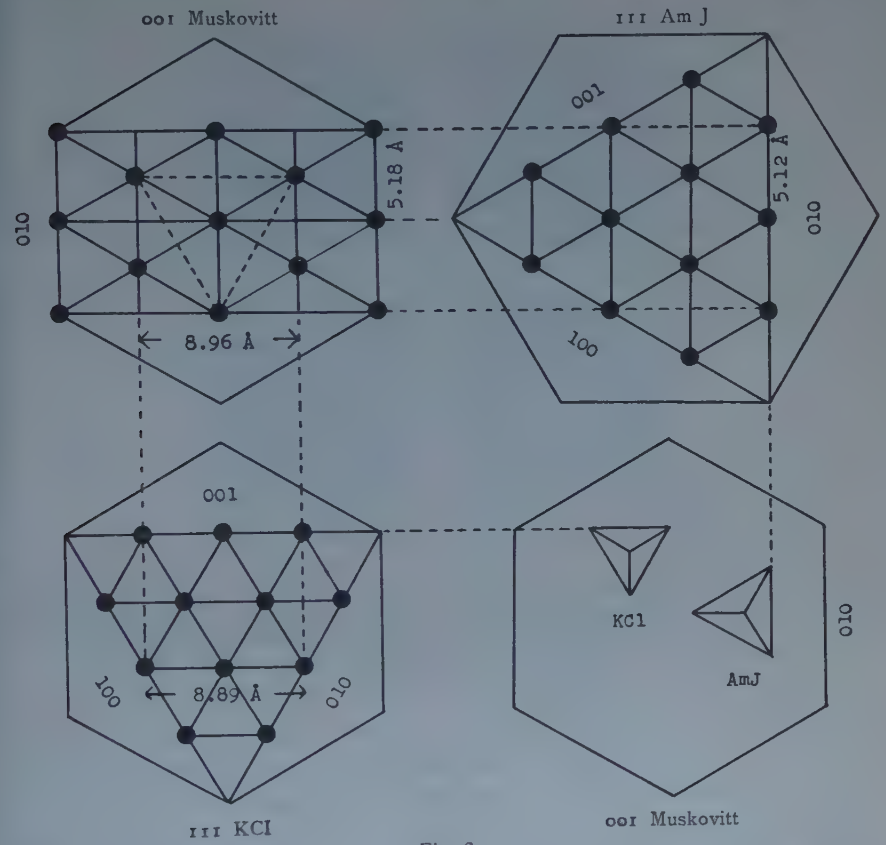


Fig. 6.

sjoner, men også kjemisk, synes å opptre hos flertallet av de naturlige regelmessige sammenvoksinger.

Av andre naturlige parallellsammenvoksinger som grunner seg på tredimensjonal strukturanalogi skal jeg bare nevne de velkjente eksempler zirkon—xenotim og sammenvoksingene i gruppen sinkblende—kopperkis—fahlerts.

Vi skal så se på noen regelmessige sammenvoksinger som grunner seg på ren todimensjonal strukturanalogi.

Påvoksing av alkalihalogenider på basisflaten av glimmer har lenge vært kjent og er blitt nøye studert av Royer. Strukturplanene i glimmernes basisflate er bygget på et heksagonalt nett bestående av likesidete trekanter hvis sidelengder varierer mellom 5.10 og 5.20 Å. Glimmernes oftest monokline symmetri viser seg ikke i et enkelt basis-

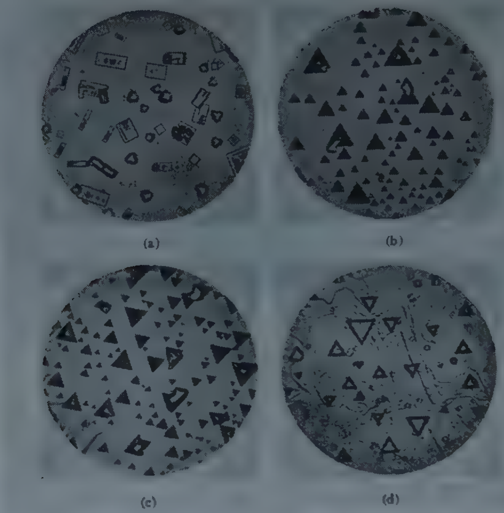


Fig. 7. Krystaller av AmJ. (a) på en glassplate — uorientert. (b) På en ubrutt spalteflate av lepidolitt — alle krystaller orientert samme vei. (c) På spalteflate av lepidolitt med usynlig „trappetrin" — to felt med motsatt orientering av krystallene. (d) På spalteflate av flogopitt — begge orienteringer statistisk fordelt.

strukturplan, men først når to eller flere slike strukturplan bygges sammen. Strukturplanene i alkalihalogenidenes oktaederflater er bygget på nett som er helt analoge med dem i glimmernes basisflater, og sidelengdene i de regulære trekanter varierer for de undersøkte halogenider mellom 3.6 Å og 6.45 Å, heri er innbefattet både NaCl- og CsCl-strukturer. Orientert påvoksing fant sted for dem som hadde trekantsider mellom 4.43 og 5.72 Å; den tilsvarende lengde for glimmer ligger noenlunde midtveis mellom disse to tall. Fig. 6 viser grunnlaget for alkalihalogenidenes orientering med (111) på glimmerens (001). Vi ser at to orienteringer symmetriske om glimmerens symmetriplan burde være like sannsynlige for halogenidkrystallene, og det viser seg også i alminnelighet at de opptrer samtidig og statistisk forfordelt. Men to spesielle tilfelle er her av interesse. Det ene gjelder KCl, hvor lengden av den nevnte trekantside er bare 4.43 Å og ligger så langt fra den tilsvarende lengde hos glimmer at den normale orientering bare sjelden finner sted. Men nå er lengden 4.43 Å meget nøyaktig lik halvdelen av glimmernettplanets dimensjon loddrett på trekantsiden, som er omtrent 8.95 Å. Derfor kan KCl også

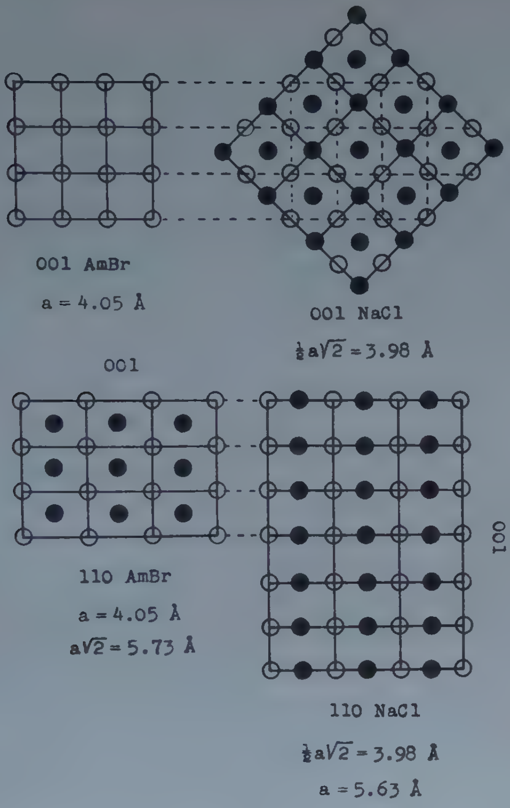
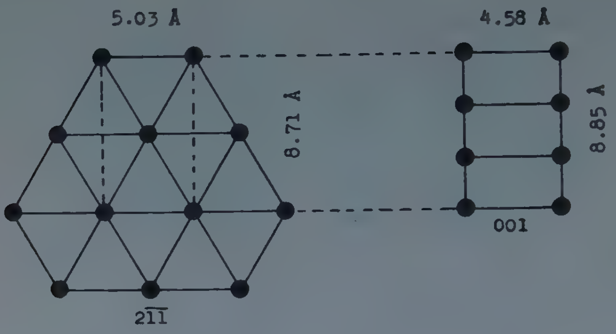


Fig. 8.

orienteres på glimmerens basis i en stilling som er dreid 90° (eller 30°) i forhold til den første, som vist på figuren. Her blir det riktignok bare koinsidens mellom et *utvalg* av de to nettplans punkter, det er altså et tilfelle av analogi mellom multiple nettmasker hos de to individer. Det annet tilfelle gjelder AmJ, hvis trekantdimensjon i (111)-flaten stemmer nesten nøyaktig overens med muskovittens i (001)-flaten. Her finner for det første den normale form for orientering sted med største letthet, men dessuten viser det seg at alle krystaller blir orientert samme vei over hele glimmerflaten, eller at en del av glimmerflaten har alle krystaller orientert den ene vei og en annen del har alle orientert den annen vei. De to orienteringer som etter glimmerens symmetri skulde være likeverdige er det altså ikke i virkeligheten. Det viser seg nå at grenselinjen på glimmerflaten mellom to områder som har AmJ-krystallene orientert motsatt er et „trappetrin“ fram-



111 Jernglans

100 Rutil

Fig. 9.

kalt ved ufullkommen spalting. Ved spalting av glimmer kan derfor nettplan med to forskjellige slags egenskaper komme til å ligge øverst. Royer sluttet herav, før glimmerens struktur var nøyere kjent, at glimmerens symmetriplan var et glide-symmetriplan, slik som den nå velkjente glimmerstruktur tydelig viser (15). På fig. 7 ser vi forsøkene med AmJ utført i praksis, her på lepidolitt, som også har meget nøye de rette dimensjoner og derfor orienterer AmJ ensidig. Vi ser her også AmJ orientert på flogopitt, hvis dimensjoner er merkbart avvikende, og her opptrer de to orienteringer atter statistisk fordelt. Bare ved meget nøye overensstemmelse i de nevnte dimensjoner kan altså glidesymmetrien gi seg synlige utslag.

Et tilfelle av regelmessig sammenvoksing på grunnlag av todimensjonal strukturanalogi mellom to kubiske alkalihalogenider er også studert av Royer. Det gjelder saltene AmBr og NaCl. Se fig. 8. AmBr har CsCl-struktur med gitterkonstant 4.05 Å, det annet NaCl-struktur med gitterkonstant 5.63 Å, og en parallellsammenvoksing på grunn av den tredimensjonale strukturanalogi er derfor ikke mulig. Derimot er $a\sqrt{2}$ for AmBr meget nær lik a for NaCl, og derav følger en meget vidtgående dimensjonsanalogi mellom strukturplanene (001) og (110) for de to krystallarter innbyrdes, riktignok slik at bare et utvalg av partiklene i den ene krystall får sitt motstykke i den annen. Analogien kommer ikke fram når krystallene står i parallellstilling, men for (001) i 45°-stilling og for (110) i 90°-stilling, slik som figuren viser. Royer fant faktisk at de to krystaller vokser sammen etter terningflaten i 45°-stilling og etter rombedodekaederflaten

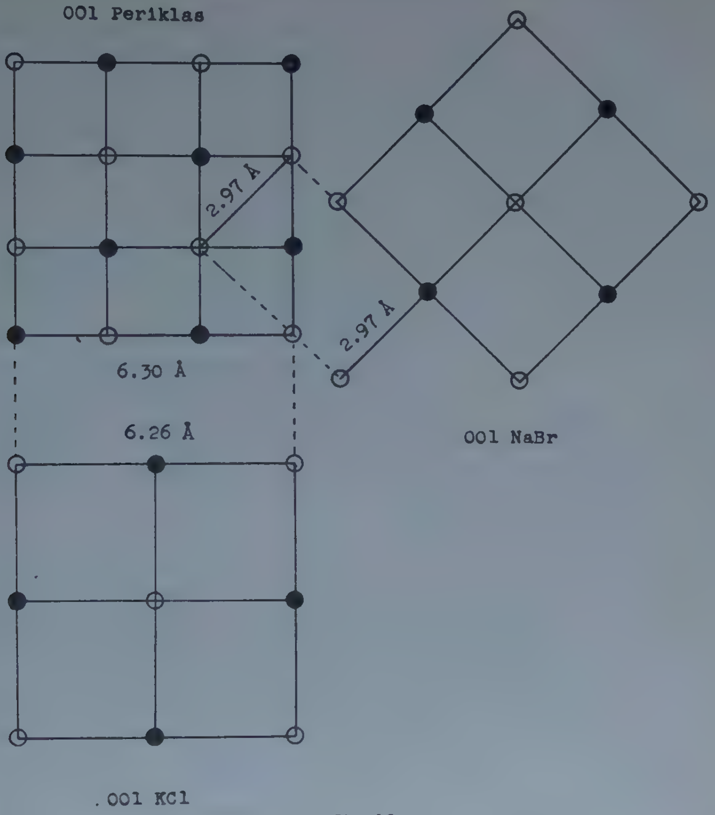


Fig. 10.

i 90°-stilling. Hvis vi altså f. eks. samtidig kunde la KCl og AmBr krystallisere på rombedodekaederflaten av en steinsaltkrystall, så vilde KCl bli orientert parallelt med steinsaltkrystallen og AmBr i en stilling loddrett på denne.

Som et eksempel fra mineralriket skal vi se på sammenvoksingen jernglans—rutil. Se fig. 9. Det heksagonale nett i jernglansens basisflate har trekantmasker med sidelengde 5.03 Å. Nettets identitetsavstand loddrett på trekantsiden er 8.71 Å. I nettplanet (100) hos rutil finner vi tilnærmet de samme dimensjoner, nemlig a = 4.58 Å og 3 c = 8.85 Å. På denne analogi, som forøvrig bare gir tilnærmet koinsidens for et *utvalg* av nettplanenes punkter, beror den sammenvoksing vi finner i naturen og som tidligere er nevnt. (Fig. 1.)

Jeg skal så nevne et av Royers forsøk som alltid ga negativt resultat. Periklas (MgO) viser i sine terning-nettplan en høg grad av dimensjons-analogi med terningnettplanene hos NaBr og hos KCl, som vist på fig. 10. Allikevel lykkes aldri her noen orientert påvoksing. Grunnen er åpenbart den at en orientering på grunnlag av den nevnte analogi vil fordre koinsidens av ioner av motsatt polaritet, som det lett ses, og som før nevnt er koinsidenser av denne art teoretisk ikke å vente. Forholdet er analogt med det av V. M. Goldschmidt innførte begrep antisomorfi. Som bekjent kan to innbyrdes antisomorfe krystaller ikke danne blandingskrystaller, selv om deres tilsvarende dimensjoner stemmer aldri så nøye overens.

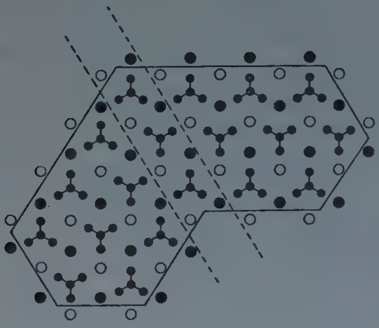


Fig. 11.

Fig. 11 viser et godt eksempel på den strukturmessige forklaring av en tvillingkrystall. Vi ser to aragonitt-individer i tvillingsammenvoksing projisert langs c-aksen. Det er her ikke bare en strukturanalogi i selve sammenvoksingsflaten, men en rekke strukturplan fortsetter ubrutt fra det ene individ og over i det annet. Strukturanalogien i tvillingstilling blir altså i en viss forstand 3-dimensjonal. Vi må jo også vente å finne et temmelig solid grunnlag for en tvillingdannelse som i naturen opptrer så hyppig som denne.

Det er ennå mange interessante enkeltheter som kunde være verd omtale. Jeg skal bare nevne en enkelt ting som Royer har gjort oppmerksom på. Kohesjonskreftene i sammenvoksingsflaten mellom to gjensidig orienterte krystaller er i de fleste tilfelle langt mindre enn kohesjonskreftene i de to krystallers indre. Dette kommer tydeligvis av at de parallellsammenvoksete nettplan ikke har *nøyaktig* samme bygning og dimensjoner, slik at en tilnærmet koinsidens av nettmasker i et punkt av sammenvoksingsflaten raskt taper seg utover til sidene på grunn av summasjonen av de små avvikelser. „Interferensen“ mellom de to nettplan fører teoretisk til at sammenvoksingsflaten består av et mer eller mindre grovdimensjonert nett av punkter med tilnærmet koinsidens. Men her spiller krystallenes mosaikkbygning og andre ufullkommenheter inn.

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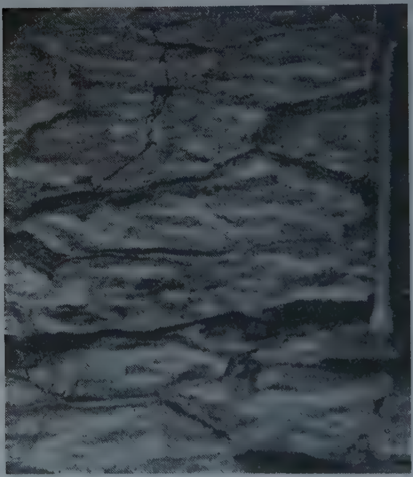
Trykt 27. november 1942.

NOTISER

TØRKESPREKKER I SILUREN PÅ RINGERIKE



Tørkesprekker fra silurlag (etasje 8 b) på Ringerike.

I Norsk geologisk tidsskrift bd. 5, hefte 1 (1918) beskriver O. Holtedahl et funn av tørkesprekker i den øvre del av den marine silur i Bærum. Laget med tørkesprekkene tilhører etasje 9 b av Ludlow eller Spirifer elevatus-avdelingen. Forekomsten viser en tørrlegning av sjøbunnen og tyder på at de yngste marine sedimenter i siluren var avleiret i grunt vann.

Sammen med stud. real. Gunnar Henningsmoen har jeg i sommer (1941) drevet geologisk-paleontologiske undersøkelser på Ringerike og Hadeland. Langs veien mellom Sundvolden og Vik ved Steinsfjorden er der under utvidelsen av veien framkommet meget gode profiler gjennom mellomste og øvre del av siluren. Ved Løkken, ca. 1 km øst for veikrysset ved Vik, er der blottet sandige lag fra Wenlock eller Spirifer plicatellus-avdelingen. Lagene tilhører øyensynlig etasje 8 b etter Kiærs inndeling. På en lagflate sees tydelige, polygonale tørkesprekker (fig.). Tørkesprekkene viser at sjøbunnen har vært helt tørrlagt en viss tid. Det er av interesse å finne tørkesprekker såpass langt ned i den marine lagrekke. Det bekrefter antakelsen om at silursedimentene i Oslofeltet i stor utstrekning har vært avleiret i et grunt hav.

Leif Størmer.

VEKTORANALYTISK FORMULERING AV GRUNNLOVEN FOR DEN GEOMETRISKE KRYSTALLOGRAFI

Det dreier seg her om ting som i en eller annen form og mere eller mindre utførlig er behandlet i alle lærebøker i krystallografi og mineralogi. Heller ikke den vektoranalytiske behandling er noe nytt, men jeg har ikke sett den gjennomført i den form som her er gitt.

Loven om krystallflatenes rasjonale akseavsnitt gjelder under forutsetning av at vi bruker visse (affine) koordinatsystemer som er tilpasset krystallens egen geometri. Et slikt koordinatsystem er karakterisert ved tre vektorer $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$, hvis retninger og relative[1] lengder er gitt ved et sett krystallografiske elementer for vedkommende krystall. Ut fra et fast punkt O kan vi med $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$ som det primitive vektortripel konstruere et rumgitter. Vi kommer til alle gitterets punkter (cellehjørner) ved å avsette fra O vektorene

$$\mathfrak{r} = u\mathfrak{a} + v\mathfrak{b} + w\mathfrak{c}$$

hvor u, v og w hver for seg etterhånden antar alle hele positive og negative verdier og null. Enhver slik vektor $\mathfrak{r}$ kalles en gittervektor; den vil avsatt fra et hvilket som helst gitterpunkt nå til et gitterpunkt, og enhver vektor som forbinder to gitterpunkter kan skrives på formen $\mathfrak{r}$.

Ethvert plan som inneholder to ikke parallelle gittervektorer vil være besatt med et regelmessig nett av gitterpunkter. Alle slike nettplan er parallelle med mulige flater på krystallen. Hvis en nettmaske har vektorene $\mathfrak{r}_1$ og $\mathfrak{r}_2$ til sider, så er planstørrelsen[2] $\mathfrak{r}_1\mathfrak{r}_2 (= -\mathfrak{r}_2\mathfrak{r}_1)$ karakteristisk for det nettplan den ligger i. Planstørrelsens tallverdi er nettmaskens flateinnhold; jo mindre den er, jo tettere er nettplanet besatt med punkter og jo større er dettes krystallografiske betydning. Hvis vi uttrykker vektorene $\mathfrak{r}_1$ og $\mathfrak{r}_2$ ved det primitive vektortripel og utfører deres ytre produkt, så får vi planstørrelsen uttrykt ved de primitive planstørrelser $\mathfrak{b}\mathfrak{c}$, $\mathfrak{c}\mathfrak{a}$ og $\mathfrak{a}\mathfrak{b}$:

$$\begin{aligned}\mathfrak{r}_1\mathfrak{r}_2 &= (u_1\mathfrak{a} + v_1\mathfrak{b} + w_1\mathfrak{c})\,(u_2\mathfrak{a} + v_2\mathfrak{b} + w_2\mathfrak{c}) = \\ &= (v_1 w_2 - v_2 w_1)\,\mathfrak{b}\mathfrak{c} + (w_1 u_2 - w_2 u_1)\,\mathfrak{c}\mathfrak{a} + (u_1 v_2 - u_2 v_1)\,\mathfrak{a}\mathfrak{b}.\end{aligned}$$

Enhver av gitterets planstørrelser har derfor hele komponenter i de primitive planstørrelser og kan skrives på formen

$$\mathfrak{r}_1\mathfrak{r}_2 = l\mathfrak{b}\mathfrak{c} + m\mathfrak{c}\mathfrak{a} + n\mathfrak{a}\mathfrak{b}.$$

Forholdet mellom akseavsnittene for et nettplan som inneholder planstørrelsen $\mathfrak{r}_1\mathfrak{r}_2$ kan vi finne ved å multiplisere planstørrelsen skalart med

---

[1] Vi ser her bort fra de grunnvektorer hvis absolutte lengder kan bestemmes røntgenografisk og som for øvrig står i en eller annen enkel sammenheng med $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$.

[2] De vektorbetegnelser som er brukt her finnes f. eks. i C. Runge, Vektoranalysis, Verlag S. Hirzel, Leipzig.

$x\mathfrak{a}$, $y\mathfrak{b}$ og $z\mathfrak{c}$ suksessive, hvor x, y og z er de ukjente akseavsnitt. Disse tre skalare produkter må nemlig være like store, da de hvert for seg betyr volumet av et parallellepiped med $\mathfrak{r}_1\mathfrak{r}_2$ som grunnflate og samme høide (nemlig nettplanets avstand fra O). Utfører vi disse produkter og setter dem like store, så får vi

$$xl = ym = zn \qquad \text{eller} \qquad x:y:z = \frac{1}{l} : \frac{1}{m} : \frac{1}{n}.$$

l, m, n er altså nettplanets resiproke akseavsnitt, d. v. s. dets millerske indises. Da enhver gittervektor er parallell med aksen for en av krystallens mulige soner og dens komponenter er proporsjonale med denne sones indises, har vi her av to soner avledet den flate som er felles for dem og funnet de kjente formler

$$l = \begin{vmatrix} v_1 w_1 \\ v_2 w_2 \end{vmatrix} \qquad m = \begin{vmatrix} w_1 u_1 \\ w_2 u_2 \end{vmatrix} \qquad n = \begin{vmatrix} u_1 v_1 \\ u_2 v_2 \end{vmatrix}$$

Analogt kan vi av indises for to ikke parallelle flater finne indises for den sone de bestemmer. Det er da hensiktsmessig istedenfor de karakteristiske planstørrelser for disse flater å betrakte deres „tilhørende vektorer“, som vi får ved å innføre vektorprodukter istedenfor ytre produkter. Til planstørrelsen $l\mathfrak{b}\mathfrak{c} + m\mathfrak{c}\mathfrak{a} + n\mathfrak{a}\mathfrak{b}$ svarer da vektoren $l\mathfrak{b}\times\mathfrak{c} + m\mathfrak{c}\times\mathfrak{a} + n\mathfrak{a}\times\mathfrak{b}$, som kan skrives $\mathfrak{a}\mathfrak{b}\mathfrak{c}\,(l\mathfrak{a}^* + m\mathfrak{b}^* + n\mathfrak{c}^*)$, hvor $\mathfrak{a}^*$, $\mathfrak{b}^*$, $\mathfrak{c}^*$ er det resiproke vektortripel til $\mathfrak{a}$, $\mathfrak{b}$, $\mathfrak{c}$. Denne vektor faller langs normalen til planstørrelsen. Produktet $\mathfrak{a}\mathfrak{b}\mathfrak{c}$ (volumet av elementærcellen) kan vi velge lik 1, slik at vektoren kan skrives $l\mathfrak{a}^* + m\mathfrak{b}^* + n\mathfrak{c}^*$. Danner vi denne vektor for hver av de to flater, så er deres vektorprodukt en vektor som er parallell med flatenes skjæringslinje, altså med aksen for deres felles sone:

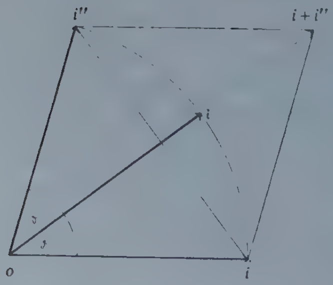
$$(l_1\mathfrak{a}^* + m_1\mathfrak{b}^* + n_1\mathfrak{c}^*) \times (l_2\mathfrak{a}^* + m_2\mathfrak{b}^* + n_2\mathfrak{c}^*) =$$
$$= (m_1 n_2 - m_2 n_1)\,\mathfrak{b}^* \times \mathfrak{c}^* + (n_1 l_2 - n_2 l_1)\,\mathfrak{c}^* \times \mathfrak{a}^* + (l_1 m_2 - l_2 m_1)\,\mathfrak{a}^* \times \mathfrak{b}^*$$

Da vi har satt $\mathfrak{a}\mathfrak{b}\mathfrak{c}$ lik 1 er også $\mathfrak{a}^*\mathfrak{b}^*\mathfrak{c}^*$ lik 1, og vektoren kan skrives

$$u\mathfrak{a} + v\mathfrak{b} + w\mathfrak{c}$$

hvor

$$u = \begin{vmatrix} m_1 n_1 \\ m_2 n_2 \end{vmatrix} \qquad v = \begin{vmatrix} n_1 l_1 \\ n_2 l_2 \end{vmatrix} \qquad w = \begin{vmatrix} l_1 m_1 \\ l_2 m_2 \end{vmatrix}$$



Dette er de kjente formler for beregning av en sones indises ut fra to av dens flaters indises. Vi ser at mens en sones indises er vektorkomponenter i krystallgitteret, er en flates indises vektorkomponenter i det resiproke gitter til dette.

Ved å gå ut fra de 4 valgte utgangsflater (koordinatplanene og enhetsflaten) og de soner de bestemmer og fortsatt anvende de to sett formler for beregning av soners og flaters indises, får vi frem soneforbindelsen mellom alle krystallens mulige flater, og vi har dermed vist at rasjonalitetsloven og soneloven er to uttrykk for ett og det samme. Hvis en flate (lmn) skal ligge i sonen $[uvw]$, så må dens normal stå loddrett på soneaksen, d. v. s. det skalare produkt

$$(la^* + mb^* + nc^*) \cdot (ua + vb + wc)$$

må forsvinne. Utfører vi produktet så får vi den kjente betingelse

$$lu + mv + nw = 0.$$

Pålegger vi det primitive vektortripel (elementærcellen) spesielle betingelser, så kan det i gitteret opptre de forskjellige symmetrielementer og kombinasjoner av disse som svarer til de 7 krystallsystemer. Vi skal bare betrakte symmetriaksene.

En dreining kan defineres ved to enhetsvektorer i og i', når vi fastsetter at deres vektorprodukt $i \times i' = \mathfrak{k} \sin \vartheta$ skal ligge i dreiningsaksen og ved sitt fortegn angi dreiningens retning. Da er ϑ, vinkelen mellom i og i', dreiningsvinkelen. Hvis dreiningens retning er slik at den overfører i i i', så overfører den i' i en ny enhetsvektor i'', som kan uttrykkes ved i og i'. Av figuren, hvor $\mathfrak{k}$ står loddrett på papiret i punktet O, ser vi at vektoren $i + i''$ faller langs i' og har lengden $2 i \cdot i' = 2 i' \cdot i'' = 2 \cos \vartheta$. Vi har altså vektorligningen

$$i'' = 2 i' \cos \vartheta - i.$$

Hvis dreiningen skal være en krystallografisk dekkbevegelse, må i, i' og i'' være krystallografisk likeverdige vektorer. Hvis altså i er en gittervektor, må også i' og i'' være gittervektorer i det samme gitter. Vi velger i og i' slik at de blir minste gittervektorer i det nettplan de ligger i. Da må komponentene av i'' i systemet i, i' være hele tall eller null. Størrelsen $2 \cos \vartheta$ må altså være et helt tall eller null. Herav følger som mulige verdier

for $\cos \vartheta$: $\qquad + 1, \quad + {}^1\!/_2, \quad 0, \quad - {}^1\!/_2, \quad \div 1.$

og for ϑ: $\qquad \pm \frac{2\pi}{1}, \quad \pm \frac{2\pi}{6}, \quad \pm \frac{2\pi}{4}, \quad \pm \frac{2\pi}{3}, \quad \pm \frac{2\pi}{2}.$

Hermed er vist at en dreining som skal være en krystallografisk dekkbevegelse, må ha en dreiningsvinkel som går opp i 2π, og det enten 1, 2, 3, 4 eller 6 ganger.

Oslo, Mineralogisk-geologisk museum,
september 1941.

Ivar Oftedal.

FUNN AV PUMPELLYITT I BERGARTER FRA OSLOFELTET

Under mikroskopering av eruptivbergarter fra Oslofeltet er jeg kommet over to forekomster av et sekundært mineral som viste seg å være pumpellyitt. Da dette mineral hittil ikke har vært påvist i Norge, kan funnet kanskje ha interesse.

Den ene forekomst er i en syenittporfyr fra Eidsfoss i Vestfold (preparatet tilhører professor W. C. Brøgger's typesamling, E. G. K. G. 156, og finnes på Geologisk museum, Tøyen). Bergarten består vesentlig av en sterkt omvandlet og uklar alkalifeltspat, som finnes i form av innsprengninger (1—2 cm lange), og som også utgjør hovedmassen av den finkornede grunnmasse. De øvrige bestanddeler av grunnmassen er angitt (i delvis idiomorfe krystaller og helt frisk), biotitt (delvis klorittisert), erts (i små, uregelmessige korn) og apatitt (i talrike, ytterst fine nåler). Dessuten finnes enkelte serpentinaggregater.

Den annen forekomst er i en diabas fra Ballerud, Østre Bærum. Diabasen opptrer i en ca. 10 m tykk, steiltstående gang i retning omtrent nord—syd. Bergarten består av sterkt omdannet plagioklas, kalifeltspat (som også er ufrisk), augitt (helt frisk), kloritt (synes delvis å være omdannet biotitt) og litt erts, kis og apatitt. Plagioklasens anortittinnhold er ca. 10 %.

I begge de nevnte bergarter forekommer det nye mineral i meget liten mengde på hulrom sammen med epidot, kalkspat og prehnitt. Det ligger innesluttet dels i prehnitt, dels i kalkspat, og synes derfor å være eldre enn disse. Dets aldersforhold til epidot lar seg ikke bringe sikkert på det rene.

Mineralet danner flattrykte, stenglige krystaller (dimensjoner opp til 0,3 . 0,1 . 0,03 mm), som enkelte steder er uregelmessig orientert, men andre steder (særlig i syenittporfyren fra Eidsfoss) er ordnet i vifteformede aggregater. Enkelte krystaller viser spalteriss ⊥ den minste dimensjon.

Mineralet har middels sterk dobbeltbrytning (høgeste interferensfarge gult av 1. orden). Enkelte snitt viser anomale blå og rødfiolette interferensfarger.

Optisk karakter: Toakset positivt. Aksevinkelen kunde ikke bestemmes, da det ikke ble funnet noe tilstrekkelig godt aksesnitt.

Aksedispersjon: $\rho < \upsilon$, meget sterk.

Optisk orientering: β ǂ krystallenes lengderetning. Vinkelen mellom γ og spalteretningen = ca. 30°.

Krystallene synes altså å være monokline og uttrukket etter b-aksen, i likhet med epidot.

Pleokroisme: α og γ fargeløse, β blågrøn.

Lysbrytning: $\beta = 1{,}695$ (målt ved immersjonsmetoden på materiale fra gangen ved Ballerud. Ifølge dobbeltbrytningens størrelse er da antakelig $\alpha =$ ca. $1{,}690$, $\gamma = 1{,}705$.

De funne optiske data stemmer helt med dem Quitzow angir for pumpellyitt (Zentralblatt für Mineralogie etc., A, 1936), og mineralet viste seg ved sammenlikning med et preparat av pumpellyitt fra Michigan å være helt lik denne. Det er derfor ingen tvil om at det virkelig er pumpellyitt.

Pumpellyitten, som har formelen $Ca_4 (Al, Fe^{III}, Fe^{II}, Mg)_6 Si_6 O_{28} (OH)_8 \cdot H_2O$, og strukturelt antakelig er beslektet med zoisitt-epidot-gruppen, ble oppdaget av Ch. Palache og H. E. Vassar i 1925 i hulrom i den kopperførende basalt ved Lake Superior. Den finnes her sammen med kloritt, kvarts, epidot, prehnitt og gedigent kopper, og er dannet senmagmatisk — hydrotermalt.

Senere er pumpellyitt funnet i en omvandlet basalt fra Haiti (Burbank 1927), i glaukofanskifer i Kalifornia (Irving, Vonsen og Gonier 1932) og i glaukofanskifer i Syd-Italia (H. W. Quitzow 1935). På det sistnevnte sted utgjør den en vesentlig bestanddel av bergarten, og må antas å være dannet sammen med glaukofan og lawsonitt under metamorfosen.

Quitzow har siden funnet pumpellyitt i en rekke omdannede diabaser fra Tyskland (beskrevet i Zentralblatt für Mineralogie etc. 1936). Han finner at den bare forekommer i diabasen hvor plagioklasen er omdannet, mens pyroksenen som regel er frisk. Derimot opptrer den aldri i diabaser med frisk plagioklas, selv om de mørke mineraler er vidtgående omdannet. Han antar derfor at den må være dannet på bekostning av plagioklasens anortittinnhold.

Dette synes også å være tilfellet i de to forekomster jeg har funnet, idet feltspaten begge steder er sterkt omdannet. Også feltspaten i syenittporfyren fra Eidsfoss må antas primært å ha vært kalkholdig på grunn av den rikelige utskillelse av epidot og kalkspat.

Summary.

In igneous rocks from the Oslo region I have found two occurrences of pumpellyite; one in a syenite porphyre from Eidsfoss, Vestfold, the other in a diabase from Bærum, W of Oslo.

In both of these rocks the feldspar is strongly decomposed, while the pyroxene is fresh. The pumpellyite occurs in microscopical crystals together with calcite, epidote and prehnite, which have probably all got their chalk from the decomposed feldspar.

The pumpellyite was identified by its index of refraction ($\beta = 1{,}695$), its optical character (biaxial positive, dispersion strong, $\rho < \upsilon$), its pleocroism (β bluish green, α and γ colorless) and its optical orientation (β ‡ the elongation of the crystals).

Egil Sæther,
stud. real.

MEDLEMSLISTE

*: livsvarig medlem.

Tallet i parentes er innvalgsåret.
(S): stifter (18. februar 1905).

Ahlmann, Hans W:son, professor. Stockholms högskola. (1919).
Asklund, Bror, statsgeolog. Sveriges geologiska undersökning, Stockholm 50. (1938).
*Bache, Laura, lektor. Nordengvegen 14, Røa, V. Aker. (1931).
*Backlund, Helge, professor. Universitetet, Uppsala. (1918).
*Balk, Robert, professor. Department of geology, Mount Holyoke College, South Hadley, Massachusetts, U. S. A. (1933).
*Barth, Tom., professor. Mineralogisk institut, Universitetet, Blindern, V. Aker. (1921).
Bergersen, Birger, professor. Tannlækehøgskolen, Oslo. (1921).
Bertheau-Hansen, Chr., bergingeniør. Rikstrygdeverket, Solligata 13, Oslo. (1942).
*Bjørlykke, Harald, dosent. Norges tekniske høgskole, Trondheim. (1923).
*Bjørlykke, K. O., professor. Norges landbrukshøgskole, Ås. (S).
Blekum, Sverre, bergingeniør. Knaben molybdengruver, Flekkefjord. (1918).
*Broch, Olaf Anton, statsgeolog. Norges geologiske undersøkelse, Oslo. (1920).
Bruun, Br., ingeniør. Holwechs laboratorium, Wessels gate 8, Oslo. (1938).
Bugge, Arne, statsgeolog. Norges geologiske undersøkelse, Oslo. (1914).
*Bugge, Carl, direktør. Norges geologiske undersøkelse, Oslo. (S).
*Bugge, Jens, assistent. Geologisk institut, Norges tekniske høgskole, Trondheim. (1940).
*Callisen, Karen, museumsinspektør. Mineralogisk og geologisk Museum, Østervoldgade 7, København K. (1917).
Carlson, Fredrik, overingeniør. Sandelsgatan 35^{V}, Stockholm, Sverige. 1919).
*Carstens, C. W., bergingeniør. Norges tekniske høgskole, Trondheim. (1911).
*Christiansen, Alex., direktør. Karl Johans gate 16, Oslo. (1914).
Dal, Adolf, lektor. Middelthuns gate 14, Oslo. (1905).
Damm, C. O. B., bergmester. Nes på Hedmark. (1905).
*Danielsen, D. A., rektor. Hornnes, Setesdal. (1905).
Dietrichson, Brynjulf, bergingeniør. Storgata 41, Moss. (1917).
Donnay, J. D. H., professor. Faculté des sciences de l'Université Laval, Boulevard de l'entente, Québec, Kanada. (1937).

Dons, Johannes A., stud. real.. Slyngvegen 14, Smestad, V. Aker. (1941).
*Eckermann, Harry von, dosent. Edeby pr. Sparreholm, Sverige. (1937).
Egeberg, F. P., ingeniør, Rådhusgata 5 b, Oslo. (1939).
*Egge, A., driftsstyrer. Glærem, Surnadal. (1930).
*Eskola, Pentti, professor. Min. inst., Universitetet, Helsingfors. (1919).
*Falck-Muus, Rolf, statsgeolog. Norges geologiske undersøkelse, Oslo. (1913).
*Falkenberg, Otto, ingeniør. Tordenskjolds plass 3, Oslo. (1914).
*Foslie, Steinar, statsgeolog. Norges geologiske undersøkelse, Oslo. (1911).
*Fægri, Knut, stipendiat. Bergens museum, Bergen. (1935).
*Føyn, Sven, lektor. Kongsberg høgere almenskole, Kongsberg. (1932).
Gavelin, Axel, overdirektör. Sveriges geologiska undersökning, Stockholm 50. (1920).
*Gleditsch, Chr., stud. real.. Boks 18, Skøyen, V. Aker. (1941).
Glømme, Hans, professor. Norges landbrukshøgskole, Ås. (1923).
Goldschmidt, V. M., professor. Geologisk museum, Oslo. (1906).
Graff, O. F., bergingeniør. Viksnes kopperverk pr. Haugesund. (1939).
*Grip, Erland, fil. lic.. Boliden, Sverige. (1938).
*Grønlie, O. T., rektor. Bodø. (1909).
Hansen, H. C. Se Storebakken.
*Hawkes, Leonard, geologist. Bedford college, Regent's Park, London N. W. 1. (1915).
*Heber, Gustav, advokat. Oscars gate 49, Oslo. (1938).
*Heber, Gustav, bygningsingeniør. Norsk teknisk byggekontroll, Oscars gate 46 b, Oslo. (1942).
*Heintz, Anatol, professor. Geologisk museum, Oslo. (1926).
Heltzen, Anders M., stud. real.. Borgundvegen 41, Ålesund. (1941).
*Helverschou, Julius, bergingeniør, disponent. Norsk diamantborings A/S, Dronningens gate 2, Oslo. (1918).
Henningsmoen, G., stud. real.. c/o Lundblad, Observatorie Terrasse 5 b, Oslo. (1941).
Hesse, P. A. Jürgen, Ing.-geolog. c/o Internationale Tiefbohr Kom. G. Itag, Celle, Hannover, Güterbahnhofstraße 5, Tyskland. (1936).
Hoel, Adolf, dosent. Svalbardkontoret, Observatoriegata 1, Oslo. (1905).
Holmboe, Jens, professor. Botanisk museum, Oslo. (1905).
*Holmsen, Andreas, bergmester. Bestun, Ullern. (S).
Holmsen, Bjarne, bergingeniør. Charlotte Andersens veg 28, V. Aker. (1941).
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Holmsen, Per, assistentgeolog. Norges geologiske undersøkelse, Oslo. (1940).
*Holtedahl, Olaf, professor. Geologisk institut, Blindern, V. Aker. (1908).
*Horn, Gunnar, bergingeniør. Svalbardkontoret, Observatoriegata 1, Oslo. (1917).
Hornemann, H. H., bergingeniør. Bestunvegen 14, Bestun. (1925).
Hvoslef, R., major. Boks 127, Oslo. (1934).

Høeg, Ove, konservator. Trondheims museum, Trondheim. (1924).
*Isachsen, Fridtjov, dosent. Geografisk institut, Blindern, V. Aker. (1929).
Jacobsen, Ruth Clementine, cand. mag.. Kronstadveg 5 b, Bergen. (1941).
Jensen, Einar, assistent. Kjemisk institut, Blindern, V. Aker. (1939).
Johne, C. T., lektor. Kragerø. (1931).
Johnson Høst, Mimi, læke. Lillestrøm. (1913).
*Kiil, Erling, bergingeniør. Brantenborgvegen 2, Slemdal, V. Aker. (1922).
Klüver, Emil, ingeniør. Statens toll-laboratorium, Oslo. (1926).
Kolderup, Carl Fred., professor. Bergens museum, Bergen. (1905).
*Kolderup, Niels-Henr., professor. Bergens museum, Bergen. (1905).
Kollerud, Marta, cand. mag. Trondheimsvegen 10, Oslo. (1919).
*Koren, Wilhelm, direktør. Buhemba mines, p. o. Musoma, Tanganyika Territory, East Africa. (1916).
Kristoffersen, Kr., konservator. Geologisk museum, Oslo. (1941).
Kvale, Anders, amanuensis. Bergens museum, Bergen. (1936).
Landmark, Einar, bergingeniør. Rådhusgata 5 b, Oslo. (1941).
Lange, Fr., lektor. Niels Juels gate 56, Oslo. (1938).
*Lenander, N. E., direktør. Nordlandsgatan 7—9, Stockholm. (1914).
*Lindley, Henry W., dr. Berlin-Lichterfelde, Weddingen Weg 56. (1928).
Lund, Kjell, direktør. A/S Sulitjelma gruver, Fr. Nansens pl. 6, Oslo. (1938).
Lund, Worm Hirsch, direktør. Jacob Fayes veg 2, Bygdøy ved Oslo. (1941).
Lund, Worm, bergingeniør. A/S Sydvaranger, Kongensgt. 5, Oslo. (1941).
*Lundby, Sven Erik, stud. ing.. Tidemannsgt. 34, Trondheim. (1937).
Lunde, Gulbrand, direktør. Hermetikkindustriens laboratorium, Stavanger. (1926).
Løddesøl, Åsulv, direktør. Det norske myrselskap, Rosenkrantzgata 8, Oslo. (1838).
*Madsen, Victor, direktør. Kastanjevej 10, København. (1906).
Magnusson, N. H., dosent. Sveriges geologiska undersökning, Stockholm 50. (1937).
Major, Robert, cand. real.. Kirkevegen 68, Oslo. (1941).
Marstrander, Henning, direktør. c/o Bureau Technique, Consortium Kampsax, Teheran, Iran. (1917).
*Marthinussen, Marius, lektor. Tommelstadgata 20, Kongsvinger. (1931).
Melkild, Olav, skuleinspektør. Nesttun pr. Bergen. (1915).
Meyer, S. Smith, bergingeniør. Evje, Setesdal. (1924).
Monsen, Astrid, konservator. Bergens museum, Bergen. (1935).
Mortensen, Odd, cand. real.. A/S Jacob Kjøde, Paradis ved Bergen. (1938).
*Natrud, Torfinn, bergingeniør. Orkla metal- A/S, Thamshamn. (1913).
Neumann, H., assistentgeolog. Norges geologiske undersøkelse, Oslo. (1940).
*Noe-Nygaard, Arne, mag. scient.. Maagevej 10, København S. (1934).
Nummedal, A. J., konservator. Universitetets oldsaksamling, Oslo. (1912).
*Nørregaard, E. M., cand. mag.. Mineralogisk og geologisk Museum, Østervoldgade 7, København K. (1917).

Oftedahl, Christoffer, stud. real.. Postboks 256, Stabekk. (1941).
*Oftedal, Ivar, konservator. Geologisk museum, Oslo. (1918).
*Orvin, A. K., bergingeniør. Håkon den godes veg 21, Vindern, V. Aker. (1913).
Ottesen, P. O., lensmann. Manger pr. Bergen. (1915).
*Oxaal, John, direktør. Electr. furnace prod. co., Sauda, Ryfylke. (1909).
Peacock, M. A., professor. Geological department, University, Toronto, Kanada. (1938).
*Petterson, Adam, bergingeniør. Lysaker ved Oslo. (1918).
*Popoff, Boris, professor. Universitåt, Kronvald bulv. 4, Riga. (1918).
Post, Lennart von, professor. Stockholms högskola, Stockholm. (1916).
Poulsen, Arthur O., bergingeniør. Niels Henrik Abels veg 31, Blindern, V. Aker. (1941).
*Quensel, Percy, professor. Stockholms högskola, Stockholm. (1916).
Ramberg, Hans, stud. real.. Mineralogisk institut, Blindern, V. Aker. (1941).
Riiber, C. C., bergmester. Store Ringveg 160, Sogn hageby. (1920).
*Rosendahl, Halvor, konservator. Geologisk museum, Oslo. (1918).
*Rosenlund, A. L., jernbanegeolog. Gardevegen 2, V. Aker ved Oslo. (1912).
Rosenqvist, Ivan Th., mag. scient.. Vegdirektoratet, Schwensens gate 6, Oslo. (1941).
Rønning, O., ingeniør. Bygdøy allé 1, Oslo. (1938).
Samuelsen, Andreas, lektor. Landåsvegen 8 c. Bergen. (1929).
*Scheumann, K H., professor. Min. Inst. Universität Leipzig. (1928).
Schøyen, Niels, bergingeniør. Sverdrups veg 14, Trondheim. (1920).
Semb, Gunnar, assistent. Geologisk institut, Norges landbrukshøgskole, Ås. (1941).
Serck-Hanssen, Klaus, ingeniør. Holmenvegen 17, V. Aker. (1941).
Smith, H. H., bergingeniør. Camilla Collets veg 6, Oslo. (1926).
Smith, S. O., direktør. Østensjø gård, Bryn, Ø. Aker. (1912).
*Sobral, José M., dr.. Avenida de los incas 3020, Buenos Aires. (1931).
Stadheim, J. Fr., bergingeniør. Schleppegrells gate 14, Oslo. (1918).
Stenvik, Kr., laborant. Geologisk museum, Oslo. (1936).
Storebakken, H. C., cand. real.. Midtstua, Kihlsbakken, Kambo ved Moss. (1940).
*Strand, Trygve, statsgeolog. Norges geologiske undersøkelse, Oslo. (1927).
*Strøm, Kaare Münster, dosent. Ivar Åsens veg 28, Vindern, V. Aker. (1932).
Støren, R., bergingeniør. Kongsberg sølvverk, Kongsberg. (1915).
*Størmer, Leif, konservator. Geologisk museum, Oslo. (1925).
Sverdrup, Einar, direktør. Store norske Spitsbergen kulkompani, Tordenskjolds gate 6, Oslo. (1938).
Thorkildsen, Birger, overingeniør. Evje nikkelverk, pr. Kristiansand S. (1915).
*Trøften, Einar, bergingeniør. Sulitjelma. (1921).

Ulrich, Frantisek, professor. Albertov 6, Praha II. (1924).
Undås, Isak, lektor. Fløenbakken 8 b, Bergen. (1931).
Villars-Dahl, Sara Marie, fru. Bjørnvegen 7, Slemdal, V. Aker. (1933).
*Vogt, Thorolf, professor. Norges tekniske høgskole, Trondheim. (1908).
Watnelie, G. A., lektor. Sarpsborg. (1913).
Wegman, C. E., dr.. Zur Hagar, Schaffhausen, Schweiz. (1925).
Werenskiold, Werner, professor. Geografisk institut, Universitetet, Blindern, V. Aker. (1909).
Weymarn, Paul von, kommandørkaptein. Jacob Ålls gate 57, Oslo. (1932).
Wiman, C., professor. Universitetet, Uppsala. (1923).
Zachariasen, William, professor. Ryerson physical laboratory, Chicago, Ill., U. S. A. (1929).
Ørvig, Tor, cand. mag.. Havna allé 9, Blindern, V. Aker. (1941).
Ånerud, Kåre, lektor. Vahl skole, Oslo. (1931).
Åsgård, Gunnar, bergmester. Vingolfveg 29, Nordstrand ved Oslo. (1921).

60	livsvarige medlemmer.
86	årsbetalende medlemmer.
146	medlemmer.

Trykt 10. februar 1943.